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Limnological Survey of Lafayette Reservoir

Tetra Tech., Inc.
Bellevue, WA

Prepared for

Corvallis Environmental Research Lab., OR

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February 1981

LIMNOLOGICAL SURVEY OF LAFAYETTE RESERVOIR

BY

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16. ABSTRACT

Lafayette Reservoir is loacated in Lafayette, California, approximately 20 miles east of San Francisco. The reservoir and its watershed are owned and operated by the East Bay Municipal Utility District (EBMUD) as an emergency standby water supply and recreational facility.

The purpose of the project was to monitor selected chemical and biological characteristics of the reservoir in order to evaluate limnological conditions before, during and after the implementation of restoration measures (hypolimnetic aeration in conjunction with alum treatment). These studies were conducted for a period of 15 months from April 1978 to June 1979. Prior to the scheduled installation of the aeration equipment, however, EBMUD abandoned restoration plans, and the monitoring program was subsequently cancelled. The results of the initial phase of these studies provide a comprehensive description of existing limnological conditions at Lafayette Reservoir. Moreover, analyses of these data provide additional information concerning the mechanisms controlling nutrient behavior in the system as well as the applicability of the proposed restoration procedures.

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We extend our appreciation to the City of Lafayette and East Bay Municipal Utilities District (EBMUD) for their cooperation. The facilities at Lafayette Reservoir as well as data collected simultaneously by EBMUD were made readily available to us during these studies. Albert D. Mahood and Stephen Shaner were responsible for the identification of phytoplankton and zooplankton, respectively; and, their assistance is greatly appreciated. For the laboratory analysis as well as assistance with the field studies we gratefully acknowledge our colleague Carrie Campbell.

1.0 INTRODUCTION

Lafayette Reservoir is located in Lafayette, California, approximately 20 miles east of San Francisco. The reservoir and its watershed are owned and operated by the East Bay Municipal Utility District (EBMUD) as an emergency standby water supply and recreational facility. It was created by an earth filled dam constructed in 1929, and was first opened to the public in 1966. Its location within a residential area, proximity to a large metropolitan area, as well as accessability to both public and private transportation have made Lafayette Reservoir an especially popular recreational facility. Recreational activities include fishing, boating, picnicing, cycling and hiking.

The purpose of the studies described in this report was to monitor selected chemical and biological characteristics of the reservoir in order to evaluate limnological conditions before, during and after the implementation of restoration measures (hypolimnetic aeration in conjunction with alum treatment). These studies were conducted for a period of 15 months from April 1978 to June 1979. Prior to the scheduled installation of the aeration equipment, however, EBMUD abandoned restoration plans, and the monitoring program was subsequently cancelled. The results of the initial phase of these studies, which are presented in this report, provide a comprehensive description of existing limnological conditions at Lafayette Reservoir. Moreover, analyses of these data provide additional information concerning the mechanisms controlling nutrient behavior in the system as well as the applicability of the proposed restoration procedures.

2.0 MATERIALS AND METHODS

2.1 RESERVOIR DESCRIPTION

Lafayette Reservoir is a monomictic eutrophic lake with sufficient dissolved nutrients to support abundant algal growth. Temperatures range from 8°C to 24°C in surface waters and from 8°C to 14°C near the lake bottom in the deepest part of the lake. Thermal stratification generally begins in March, followed by rapid depletion of hypolimnetic dissolved oxygen. Anoxic conditions typically prevail in the hypolimnion from July through November when the lake destratifies.

At maximum capacity, Lafayette Reservoir has a volume of 5.26×10^6 m^3, a surface area of 55.8 ha and a maximum depth of 25 m. The reservoir volume is quite stable. Water levels typically vary less than 1.5 m per year and average about 135.7 m of elevation. The area-capacity curves presented in Figure 2-1 show that this elevation corresponds to an average volume of 4.5×10^6 m^3 and an average surface area of 50 ha.

The basin watershed is relatively small (336 ha), and runoff into the reservoir is limited. In the past, the water level has been maintained by importing water from the Mokelumne River which is located in the Central Valley of California. During the period these studies were conducted, however, the water level was maintained by direct precipitation and runoff.

Important morphological characteristics as well as annual hydrologic variables recorded during the period of this study are summarized in Table 2-1.

2.2 SAMPLING AND ANALYTICAL METHODS

Sampling was conducted at Lafayette Reservoir between April 1978 and June 1979. During this period, selected physical and chemical parameters as well as temporal variations in the abundance of phytoplankton,

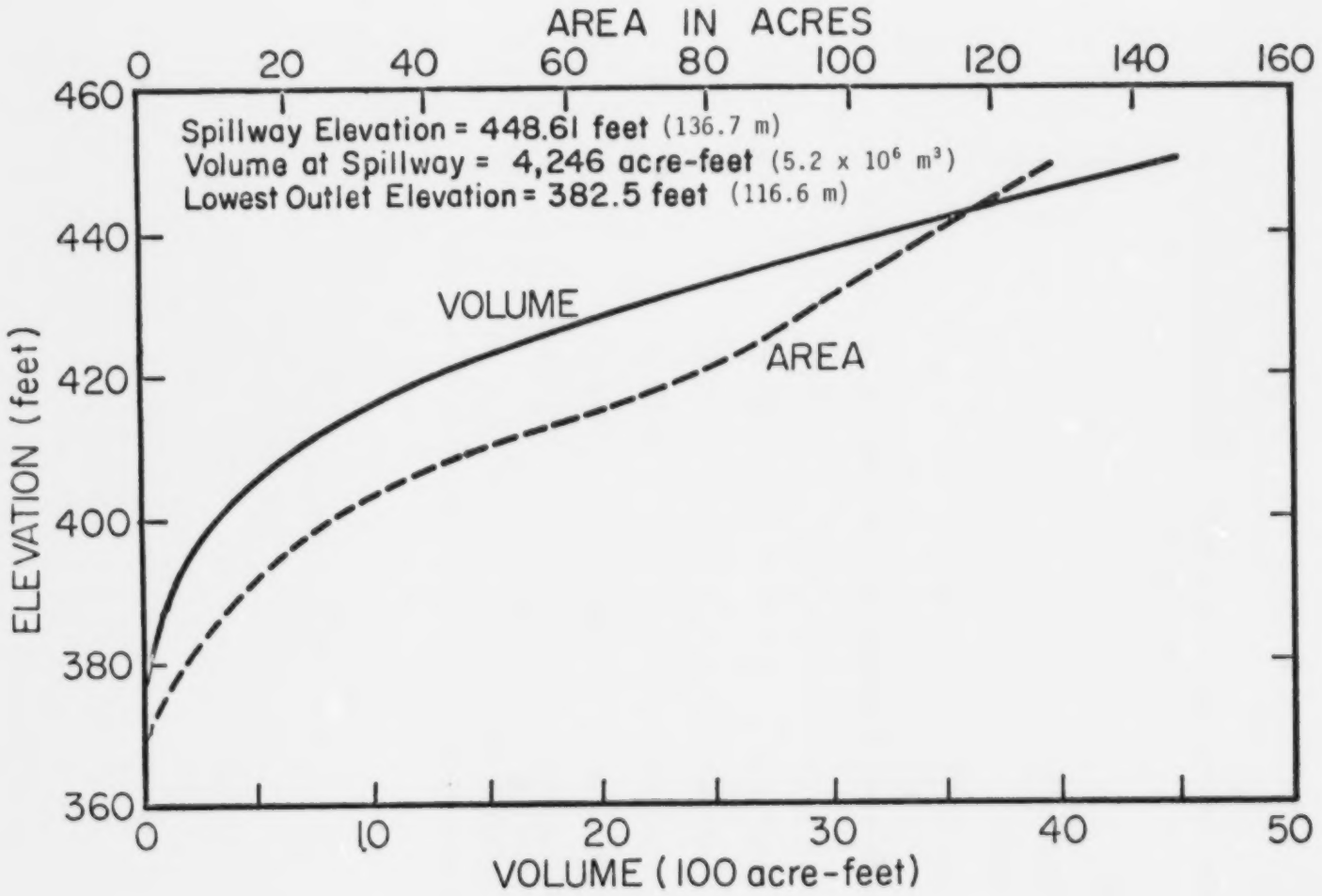

FIGURE 2-1. AREA - CAPACITY CURVES FOR LAFAYETTE RESERVOIR (AFTER EBMUD, 1976)

Table 2-1

LAFAYETTE RESERVOIR CHARACTERISTICS

Area:	55.8 ha
Volume:	5.26×10^6 m^3
Maximum depth:	25 m
Mean depth:	9.4 m
Drainage basin area:	336 ha
Annual hydrologic variables (1 July 1978 to 30 June 1979)	
rainfall on reservoir (in)	312000 m^3
runoff (in)	406000 m^3
discharge (out)	67400 m^3
evaporation (out)	644000 m^3
net change in storage (out)	7000 m^3
volume/inflow	7.67 yrs
volume/outflow	71.1 yrs

zooplankton and benthic invertebrates were routinely monitored. Sampling was conducted on several occasions in order to determine fish species composition and distribution, and angler surveys were conducted to estimate the fish catch rate. The shoreline as well as several areas within the littoral zone were surveyed in order to document the areal extent of both emergent and submergent macrophytes.

The locations of sampling stations referenced in this report are shown in Figure 2-2. The methods as well as the frequency of sampling are described below.

2.2.1 Water Quality and Materials Balances

Water quality sampling was conducted on Lafayette Reservoir from 10 May 1978 to 20 June 1979. Samples were collected on a weekly basis during the summer, but the frequency was then reduced to monthly intervals during the fall and winter. Samples were collected at a single location (station S-1, Figure 2-2) in the deepest portion of the reservoir near the dam. On each sampling date whole water samples were collected at 2-meter intervals; however, additional samples were collected within the metalimnion during periods of thermal stratification. The parameters monitored as well as analytical procedures used are listed in Table 2-2.

Nutrient concentrations of the runoff carried watershed materials were monitored on six different occasions during the study. Samples were collected at several different locations around the reservoir on each occasion. During two different storm events serial sampling was conducted in order to determine variation in nutrient concentrations with time. Samples were collected in a light rain during the initial stages of the storm event, approximately 3 hours after heavy rains and again approximately 24 hours after the initial precipitation was recorded.

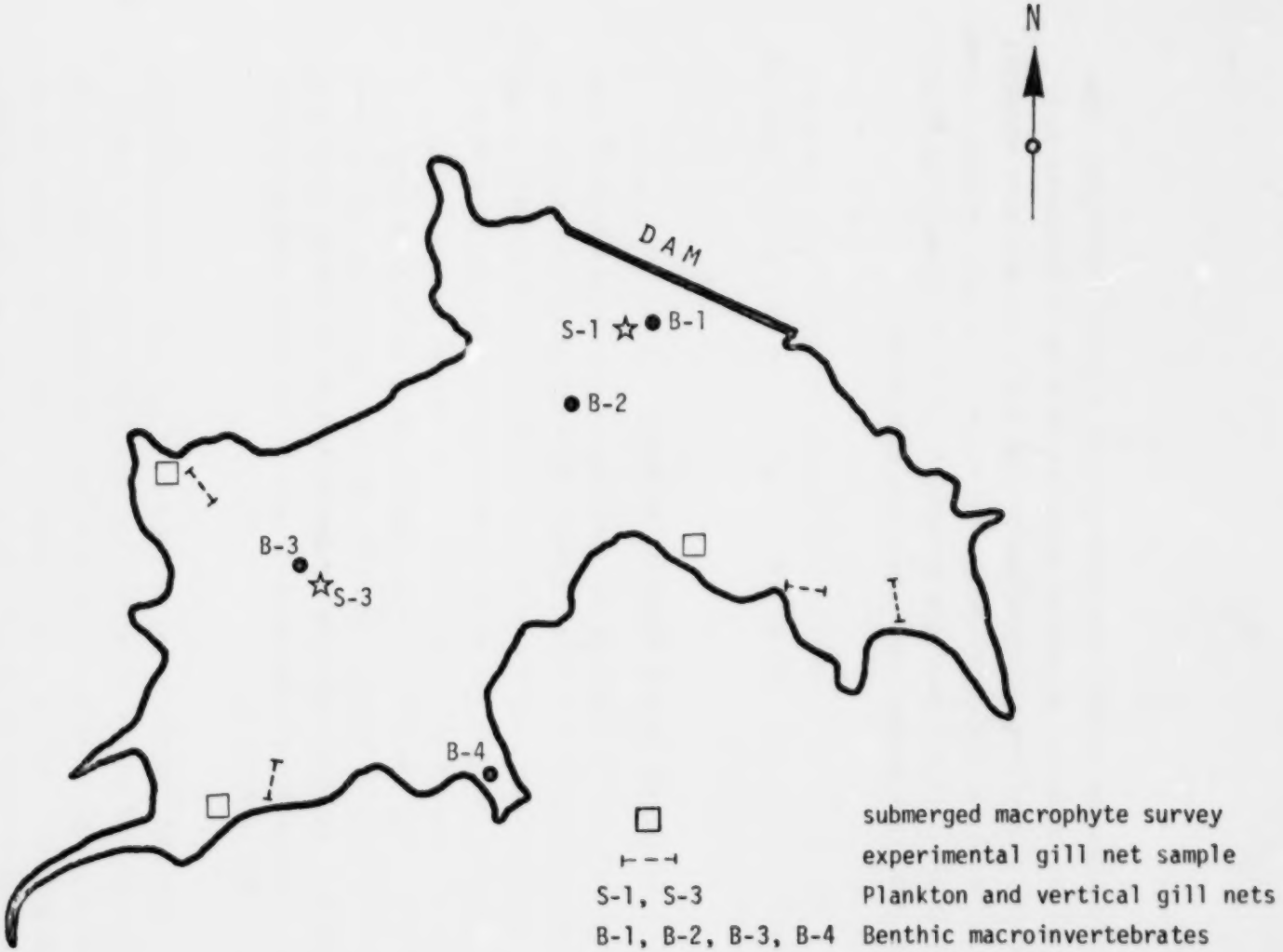

FIGURE 2-2. LOCATION OF SAMPLING STATIONS AT LAFAYETTE RESERVOIR

Table 2-2

WATER QUALITY PARAMETERS MONITORED IN LAFAYETTE RESERVOIR AND ANALYTICAL PROCEDURES

Parameter	Procedure	Reference
Alkalinity	Potentiometric titration method	APHA, 1976
Ammonia	Selective ion electrode method	EPA, 1974
Nitrate	Cadmium reduction method followed by diazotization method for determination of nitrite	APHA, 1976
Nitrite	Diazotization method	APHA, 1976 and Strickland and Parsons, 1972
Nitrogen, organic	Kjehldahl distillation	APHA, 1976
Oxygen, dissolved	Winkler iodometric method	APHA, 1976
pH	Glass electrode method	APHA, 1976
Phosphate, total, ortho and soluble	Ascorbic acid method persulfate digestion method for total phosphorus	APHA, 1976
Temperature	YSI Tele-thermometer series 400 probe	

2.2.2 Phytoplankton

Whole water samples for phytoplankton identification and enumeration were collected at a single station (S-1, see Figure 2-2) at depths of 0.5, 4.5 and 9.5 m from 25 April 1978 to 20 June 1979. Samples were collected on a monthly basis except during the summer sampling period (18 July through 19 September 1978) when samples were collected weekly. Chlorophyll-a and phaeophytin-a concentrations were measured at depths of 0.5 m, 6.0 m, 8.0 m, 12.0 m and 18.0 on all sampling dates after 18 July 1978.

Samples to be used for phytoplankton identification and enumeration were preserved in 1 percent Lugol's solution and stored in the dark prior to laboratory examination. In the laboratory, 50-100 mℓ aliquots of the 1-liter preserved samples were placed in settling chambers and examined on an inverted microscope. A minimum of 250 organisms were counted in each sample. The most common organisms were identified to the species level while less frequently encountered organisms were generally identified to the level of genus.

Spectrophotometric methods were used for the determination of chlorophyll-a and phaeophytin-a concentrations at selected sampling depths. Whole water samples (250-1000 mℓ) were filtered through 0.45 µm membrane filters. The concentration of pigments in membrane filter extracts (90% acetone) was determined with a Bausch and Lomb Model 21 spectrophotometer using a cuvette with a 5-cm path length.

2.2.3 Zooplankton

Zooplankton samples were collected at station S-1 during the period of 6 June 1978 to 20 June 1979. Samples were collected at weekly intervals during the summer and at monthly intervals during the remainder of the year.

Samples were collected at four depths (0.5 m, 5 m, 9.5 m and 18.5 m) using a submerged pump system incorporating a 12-volt centrifugal bilge pump. Water was pumped to the surface through a 1.6-cm (ID) plastic hose. All samples were filtered at the surface through a conical nylon

plankton net with 80 μm mesh. Each zooplankton sample consisted of a filtered volume of approximately 57 ℓ. Although the system displayed little variability in pumping rate throughout the study, the system was calibrated before and after each sample was collected. The calibration procedure consisted of measuring the time required to fill a known volume with pumped water. The filtered volume could then be calculated from the measured pumping rate.

Following the 5-minute pumping period, the net was thoroughly rinsed from the outside. All zooplankton samples were then preserved immediately in a 5% buffered formalin solution.

Two zooplankton samples were collected at each depth on each date. One set of samples was analyzed for dry weight and the other was used for species identification and abundance estimates. Dry-weight determinations were conducted by filtering the sample on a pre-rinsed, dried and tared glass fiber filter. The filter was then dried at 90°C for 24 hours. Filters were then weighed on an analytical balance to the nearest 0.1 mg.

Zooplankton abundance estimates were determined according to the Sedgwick-Rafter Technique described in APHA (1976). A minimum of 300 organisms was enumerated from each sample. Organism densities were calculated according to the following formula:

$$\text{Number of organisms per liter} = \frac{(\text{Number Counted}) \times (\text{Sample Volume})}{(\text{Chamber Volume}) \times (\text{Filtered Volume})}$$

Only monthly samples collected at the surface and 5-m depths were used for species identification.

2.2.4 Benthic Invertebrates

Benthic macroinvertebrate samples were collected at four stations (B-1 to B-4, Figure 2-2) on eight dates between 25 April 1978 and 19

June 1979. Representative sampling sites were selected from both the profundal and littoral zones. Stations B-1, B-2 and B-3 were positioned along the long axis of the reservoir at maximum depths of 19, 21 and 10 m, respectively. The littoral station (B-4) was located within a small cove at a depth of 3.5 m.

Three replicate Ekman dredge (0.023 m^2) samples were collected at each station location. Benthic grab samples were initially sieved (0.5-mm mesh openings) and fixed with 10% buffered formalin in the field. Samples were later sorted in the laboratory, and macroinvertebrates from each of the three grabs were identified and enumerated. The dry weight biomass of two of the three replicates from each station was determined by drying the sample at 90°C for 24 hours and weighing on an analytical balance.

Temperature and dissolved oxygen concentration were measured near the bottom prior to the time of grab sample collection. Temperature above the substrate was measured with a YSI Tele-Thermometer (Series 400 probe), and the dissolved oxygen of a whole water sample was determined using the Winkler iodometric method (APHA, 1976).

2.2.5 Fish

The fish studies at Lafayette Reservoir were divided into two main components: angler surveys and species composition-distribution.

Angler interviews were conducted on 20 dates from 23 June 1978 to 6 March 1979. All interviews were conducted between 1400 and 1600 on the indicated dates (Table 3-10). Figure 2-3 is an example of the reporting form used in the survey. In addition to recording the number and species of all fish caught, all trout were weighed to the nearest gram with a portable scale.

LAFAYETTE RESERVOIR FISHERY SURVEY

Date _____ Time _____

a. Number in group _____

b. Total hours fished _____

c. a x b = _____ (total person-hours)

d. Location of anglers: Bank _____ Boat _____

e. Type of angling: Bait _____ Lure _____

Troll _____ Other _____

f. Catch information (record weight and length if possible):

Species	Number	Length in cm (weight in grams)
Trout	_____	
Catfish	_____	
Bass	_____	
Crappie	_____	
Bluegill	_____	
Other	_____	

g. Number and type of fish released:

h. Angler's perception of fishing quality:

FIGURE 2-3. EXAMPLE OF REPORTING FORM USED IN ANGLER INTERVIEWS

The fish communities were sampled by gill net to determine both species composition and vertical distribution. Sites used for experimental gill net sets are identified in Figure 2-2. Experimental gill nets were 15.2 m long with five panels with stretched mesh sizes ranging from 4 to 10 cm. Nets were fished on the lake bottom with the small mesh panel near shore at all shoreline sites. At the deep-water site near S-1 (Figure 2-2), experimental gill nets were set in both bottom and surface configurations.

Vertical gill nets used to determine fish depth distribution were 1.8 m wide with a stretched mesh size of 7 cm. The mesh size was selected to be optimal for the collection of 23-28 cm trout stocked in Lafayette Reservoir. The nets were mounted on floating rollers and extended from the bottom to 0.5 m below the surface. The nets were checked each morning during the indicated study periods. The position of each collected fish was recorded upon net retrieval.

During the period of 16-24 August 1978, vertical gill nets were set at sites S-1 and S-3 (Figure 2-2). An additional winter survey was conducted at site S-1 during 3-9 January 1979.

2.2.6 Macrophytes

An aerial photographic survey of the reservoir's shoreline was conducted on 3 August 1978 for the purpose of mapping emergent vegetation. The shoreline was photographed along four transects at a scale of 1:2400. Additionally, a single exposure was made of the reservoir and the drainage basin at a scale of 1:12,000.

Original 9 x 9 inch Kodak IR Aerofilm transparencies were used to produce a map delineating emergent macrophyte stands. The macrophyte stands were easily distinguishable on the basis of pronounced differences in color, tone, and texture produced in the color IR transparencies. In conjunction with the photointerpretation, a ground-truth

survey was conducted in order to check the accuracy of the map as well as to collect plant specimens for taxonomic identification. The areal extent of individual stands on the reservoir was measured from the prepared map using a planimeter.

A preliminary survey was conducted at three sites on the reservoir on 27 September 1978 to determine the depth distribution of submerged macrophytes in the littoral zone. Surveys were subsequently conducted in these areas to determine the density of submerged vegetation, as measured by biomass per unit area, and the species composition within these plant assemblages. On 8 November and 30 November 1978 macrophyte samples were collected by removing all vegetation within 0.25 m^2 quadrats using a diver operated suction device. Diver observations were also made in the littoral zone to document the depth distribution of submerged vegetation.

3.0 RESULTS

3.1 WATER QUALITY AND MATERIALS BALANCES FOR LAFAYETTE RESERVOIR

The water quality data collected from 10 May 1978 to 20 June 1979 are included as Appendix A. The results of the laboratory analysis of runoff samples are summarized in Appendix B.

3.1.1 Water Balance

The hydrologic balance for Lafayette Reservoir (data provided by East Bay Municipal Utility District) shows that essentially all of the water is derived from precipitation, either directly or by runoff (Table 2-1). There is no inflow from upstream watersheds, and the small basin watershed (336 ha) and lake area (56 ha) enforce a relatively long mean residence time of 92 months. Because evaporation (644,400 m^3, 1 July 1978 to 30 June 1979) accounts for about 90% of the reservoir water loss, nutrients that enter the reservoir essentially remain there. Outflow by discharge accounted for 10% of the output with evaporation accounting for the remainder.

The consequences of this water balance are that nutrient materials have a continual low level input controlled by precipitation intensity patterns. All of the nutrient inputs to Lafayette Reservoir are derived from rainfall or from the runoff-carried watershed materials. Nutrient output is minimal and much less than input and again depends on precipitation patterns. Nutrient dynamics are relatively unaffected by inputs or outputs and vary with the seasonal and chemical state of the reservoir; i.e., the annual cycle of light, temperature and redox potential.

3.1.2 Temperature, Chemical and Nutrient Dynamics

3.1.2.1 Temperature

Lafayette Reservoir was thermally stratified when water quality sampling was initiated in May and remained so until late November (Figure 3-1). In mid-summer the metalimnion extended from 6.5 to 9.5 m. At this time the reservoir had the following proportions of the total volume in each of the depth strata: epilimnion, 56 percent; metalimnion, 18 percent; hypolimnion, 26 percent. The reservoir remained stratified until late November, at which time it became isothermal at about 12°C. The reservoir was still isothermal at 9°C in January but was essentially completely stratified again by February 1979. The minimum temperature for the total reservoir varied between 8.9°C in January and 19.3°C in July-August (Figure 3-2).

3.1.2.2 Dissolved Oxygen

With the onset of sampling in May, most of the dissolved oxygen in the hypolimnion was already depleted (Figure 3-3). Immediately after fall turnover (late November-early December), the dissolved oxygen levels did not vary with depth. However, at this time the entire lake was only 50 to 60 percent of saturation (6 mg/ℓ at 12°C, Figure 3-4). By mid-January the surface waters had increased to about 85 percent saturation; however, at water depths greater than 12 m, the oxygen saturation was only about 70 percent. In February when stratification had reoccurred, saturation was at its highest (95%) and then began to decrease to less than 45% by June. Oxygen depletion occurred in the hypolimnion while decreases according to saturation/temperature relationships occurred in the epilimnion. However, there was depletion of oxygen throughout the water column since dissolved oxygen levels were usually below saturation even in the epilimnion.

The relatively constant volume permitted the assessment of changes in the total mass of biologically important chemicals in Lafayette Reservoir during the 14 month period of study. The total mass of each

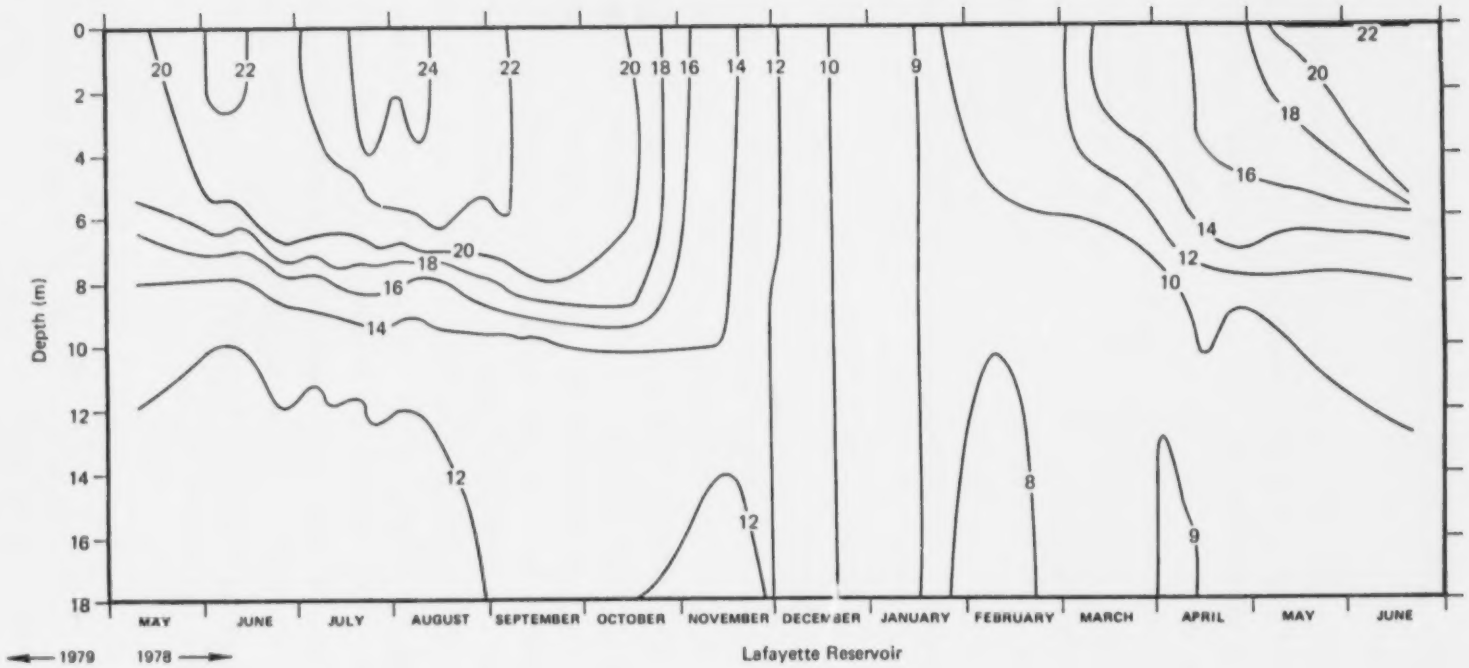

FIGURE 3-1. DEPTH-TIME DIAGRAM OF TEMPERATURE ISOPLETHS AT LAFAYETTE RESERVOIR

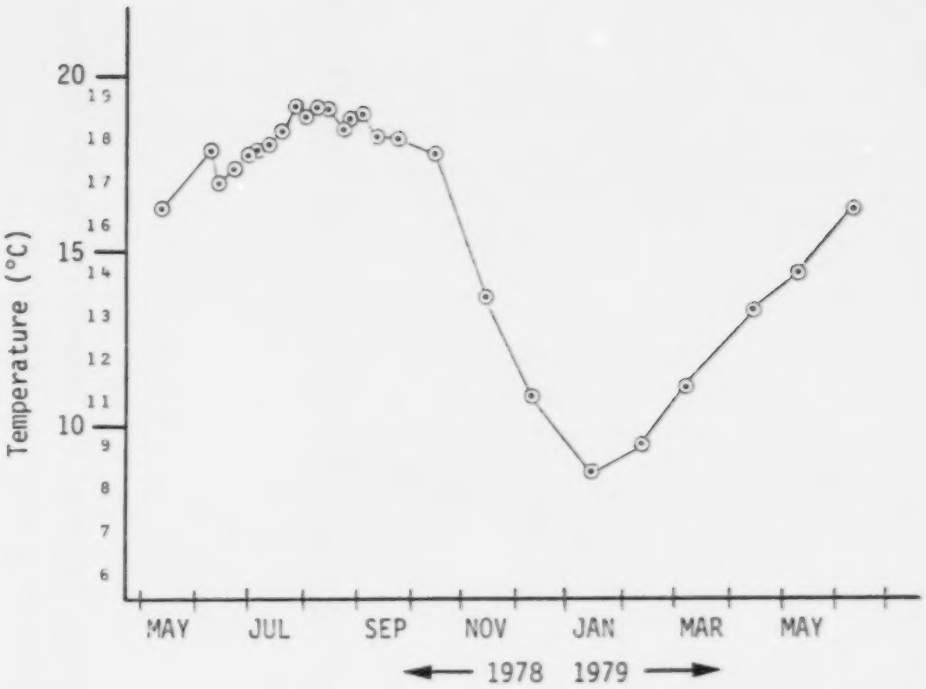

FIGURE 3-2. MEAN WATER COLUMN TEMPERATURE IN LAFAYETTE RESERVOIR

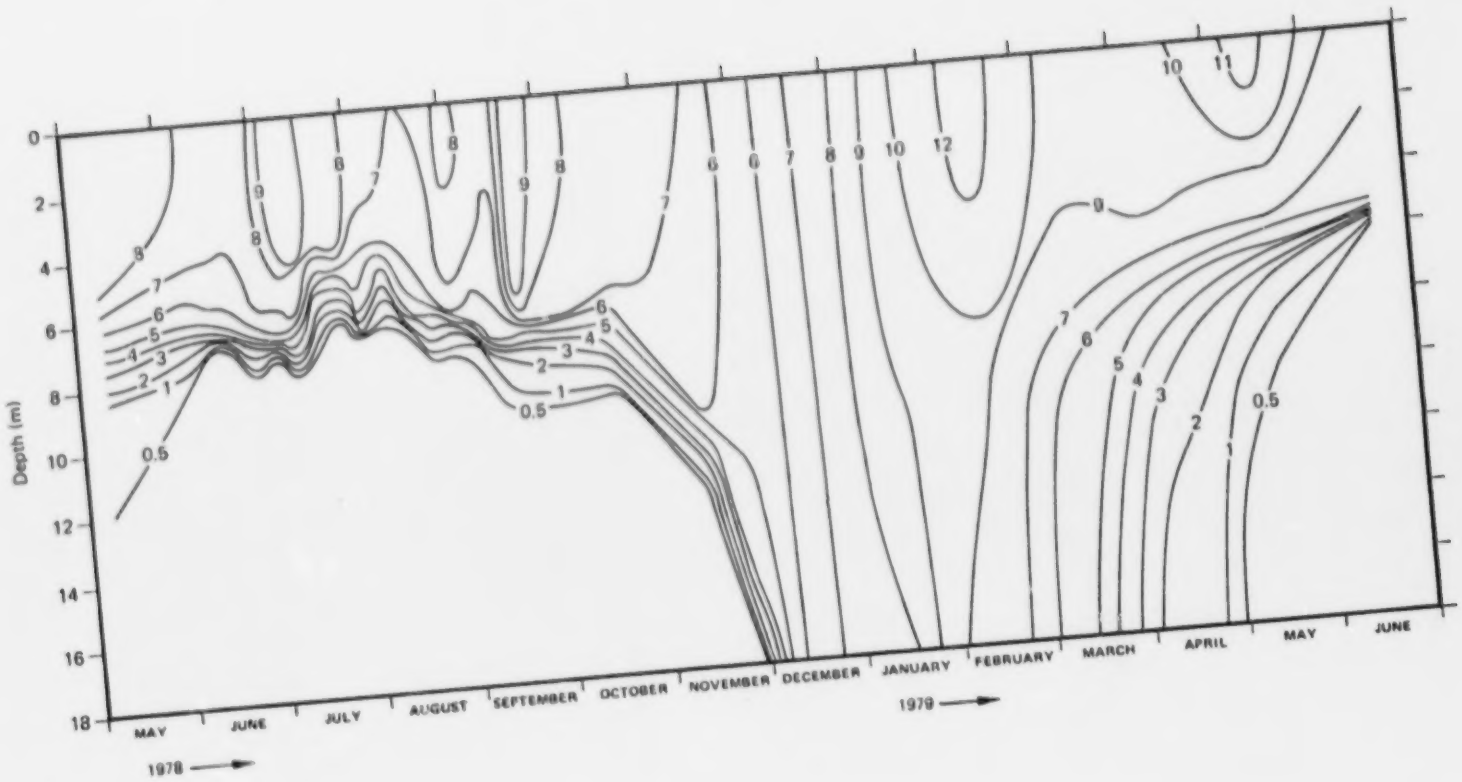

FIGURE 3-3. DEPTH-TIME DIAGRAM OF DISSOLVED OXYGEN CONCENTRATION ISOPLETHS AT LAFAYETTE RESERVOIR

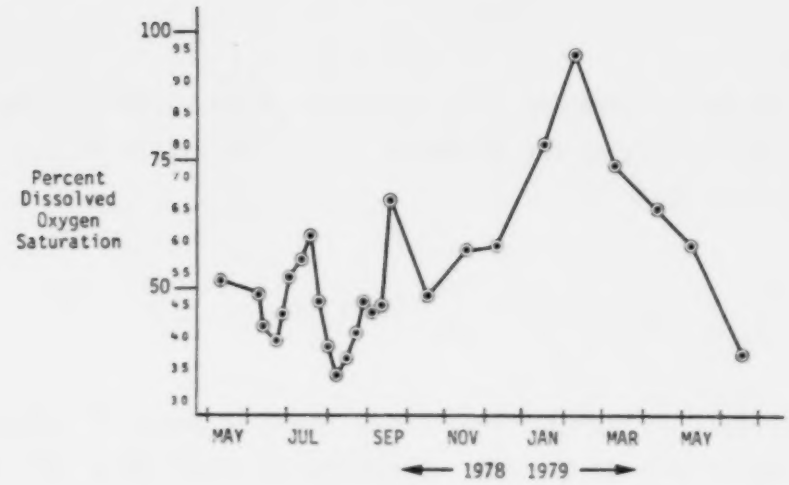

FIGURE 3-4. PERCENTAGE SATURATION OF DISSOLVED OXYGEN IN LAFAYETTE RESERVOIR

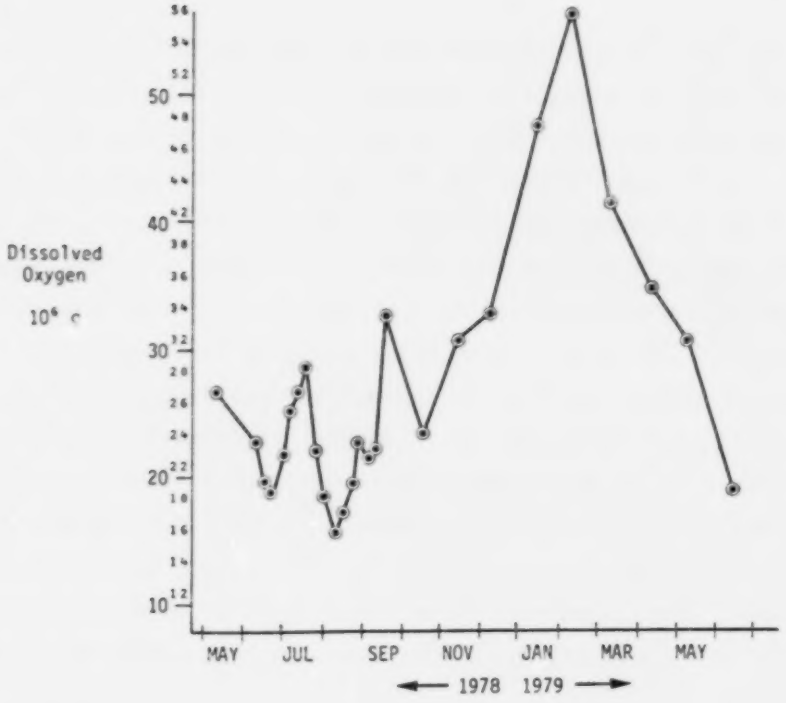

FIGURE 3-5. TOTAL MASS OF DISSOLVED OXYGEN IN LAFAYETTE RESERVOIR

material studied was computed using the mean concentration (C_i) in a layer (i) and multiplying the concentration by the volume of the layer and summing over depth (Z):

$$\text{total mass} = \sum_{i=1}^{i=Z} (C_i) \cdot (V_i)$$

There was minimal variation (range <5% of mean) in depth of Lafayette Reservoir and so an average layer volume was used throughout the year.

The total mass of dissolved oxygen varied by a factor of nearly four throughout the study period (Figure 3-5). The rate of increase in dissolved oxygen over the period October to February averaged 0.5 $g/m^2/day$.

Assuming that sediment oxygen demand (SOD) accounted for the removal of dissolved oxygen from Lafayette Reservoir during the sampling period of February to June 1979 (125 days) and the mean reservoir temperature for 20 June 1979 of 16.5°C had a corresponding saturation level for dissolved oxygen of 9.8 µg/ℓ, the SOD can be calculated to be 0.26 g $O_2/m^2/day$ (Sonzogni et al., 1977). The range of areal hypolimnetic oxygen demand reported by Cornett and Rigler (1979) was estimated as 0.05 to 0.36 g $O_2/m^2/day$. Medine et al. (1980) reviewed previous sediment oxygen demand studies and showed a broad range of values for laboratory and field measurements. Inherent in these values is additional variance due to measurements being made at different temperatures. Closely controlled laboratory measurements of SOD using sediments from a highly eutrophic lake ranged between 0.40 to 0.45 g $O_2/m^2/day$ (Medine et al., 1980). Thus, Lafayette Reservoir was intermediate in its sediment oxygen demand but certainly within the range of eutrophic lakes and reservoirs.

3.1.2.3 Total Inorganic Carbon

The mass of inorganic carbon (TIC) was calculated from alkalinity, pH and temperature relationships assuming that all of the measured alkalinity was due to appropriate inorganic carbon forms and that the TIC system was at chemical equilibrium (method from Saunders et al., 1962). This approximation is reasonable if other weak acid salts are at low concentrations.

Two distinct periods are defined by the TIC total mass in Lafayette Reservoir (Figure 3-6): high levels of TIC from August through December and low levels the remaining months. The February to July period coincides approximately with the major photosynthetic activity of the year. Mean TIC for this period was 183000 kg (n=9) and for the remainder of the study averaged 190,000 kg (n=15). Also, the pH values during the February to July period were higher indicating greater photosynthetic activity. Since TIC was not appreciably affected by inflows and outflows, the dynamics must be in response to physical, chemical and biological processes in the reservoir.

Mixing and stratification in combination with photosynthesis and respiration processes, appear to be responsible for the changes in TIC. However, the change in total masses of TIC and dissolved oxygen are not well correlated (r=-0.29) although the slope is negative as would be expected. The spatial and temporal separation of photosynthesis and respiration preclude defining their interrelationship by calculating overall lake carbon and oxygen dynamics.

3.1.2.4 Phosphorus

The average epilimnion (0-6 meters) concentrations of orthophosphate (reactive) phosphorus, total dissolved, and total phosphorus from May 1978 through June 1979 are quite typical of eutrophic lakes. Relatively constant concentrations through the summer followed by marked increases during the fall overturn (October-November) were observed (Figure 3-7).

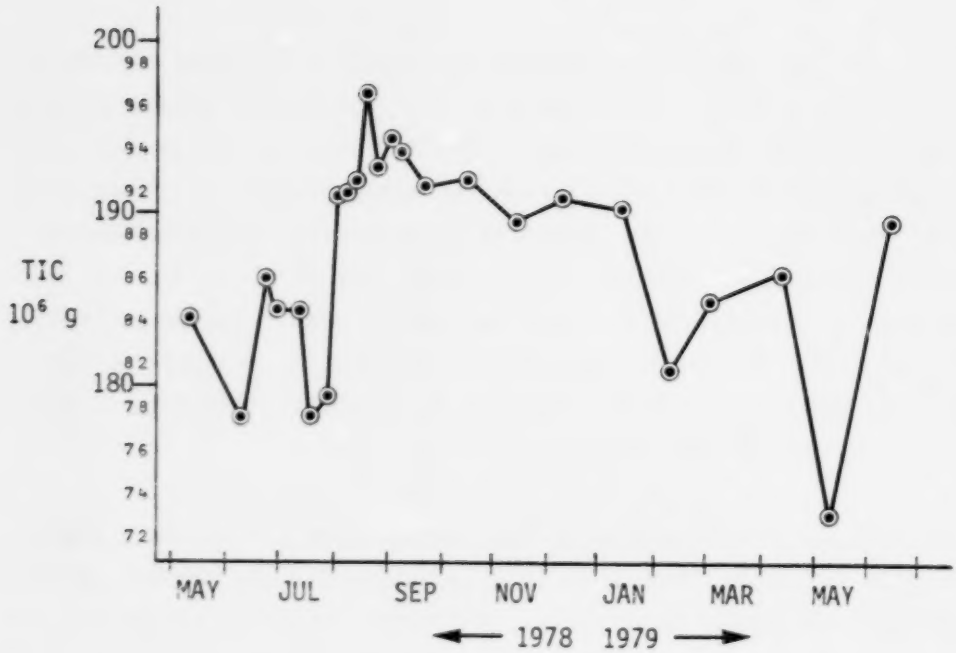

FIGURE 3-6. CALCULATED TOTAL MASS OF INORGANIC CARBON IN LAFAYETTE RESERVOIR

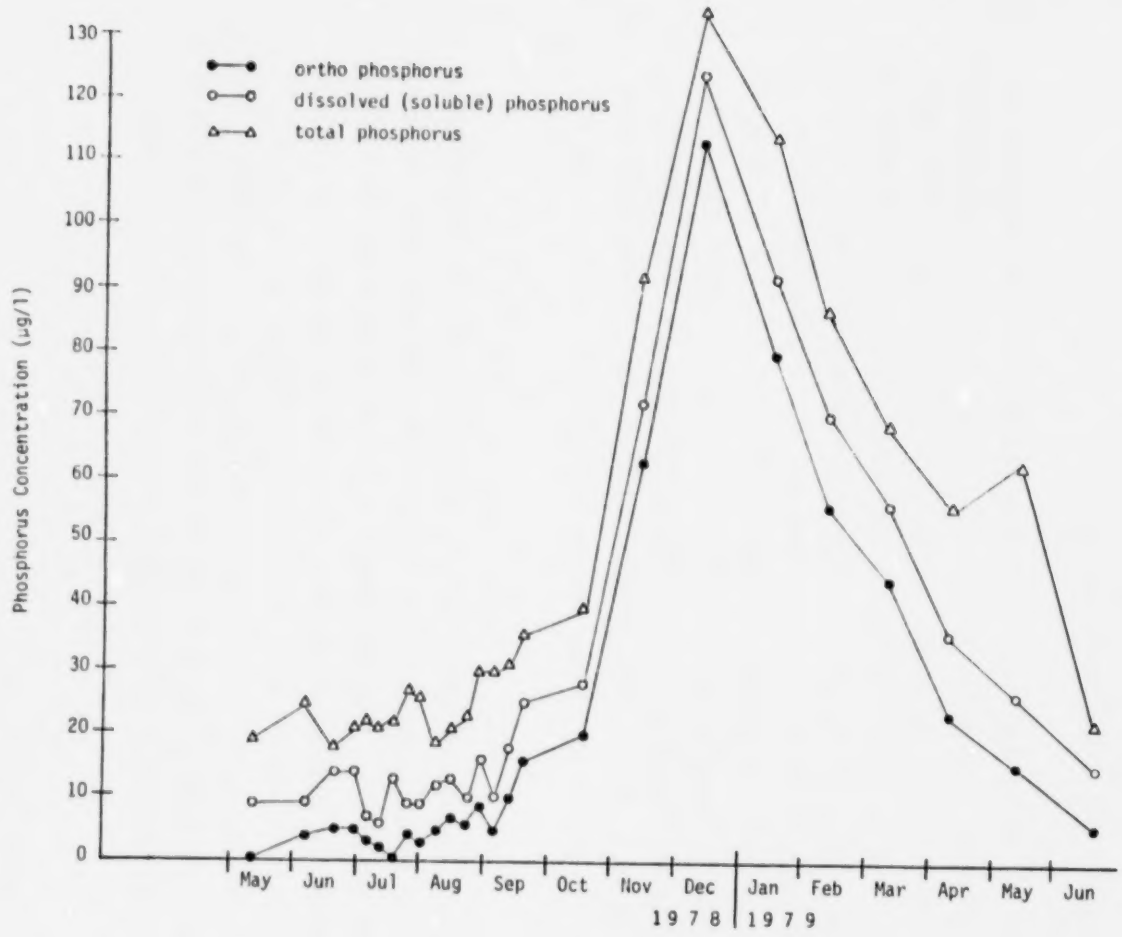

FIGURE 3-7. PHOSPHORUS CONCENTRATIONS IN THE EPILIMNION (0-6 M)

Hypolimnion phosphorus concentrations (Figure 3-8) show a continuous increase through the summer until fall overturn, at which time there was a rapid decrease in concentrations. It is interesting to note that the concentrations of dissolved and orthophosphate phosphorus increase at a remarkably uniform rate, probably from sediment release. The difference between dissolved and total phosphorus indicates the probable rate of plankton and detritus accumulation and degradation.

Figure 3-9 shows the total mass of phosphorus in the reservoir as a function of time. These data clearly show the release of phosphorus from the sediments and the rapid redeposition at the time of fall overturn. There was no hydraulic outflow during the period May-December of 1978 and the major inflows were in January, February and March. The rate of sediment release was a very constant 3.7 kg/day from May to October. Based on the approximate area of the hypolimnion (10 m depth contour contains 295,000 m^2), the release rate was 13 $mg/m^2/day$. The release rates are about 30% higher than other maximum rates reported (Sonzogni et al., 1977). From October to April the redeposition rate was 2.7 kg/day or 5.2 $mg/m^2/day$ (using entire surface area of 560,000 m^2).

Sediment phosphorus data shown in Table 3-1 indicate an average concentration of approximately 700 mg/kg of dry sediment (approximately 350 g/m^3 of sediment). The phosphorus released between May and October (585 kg) would be equivalent to that contained in the top 6 mm of hypolimnetic sediment. Using acid extractable phosphorus as the source of phosphorus release would require approximately 25 cm of sediment. The high concentration of total iron in the sediments is consistent with a classical iron-phosphate precipitation mechanism dependent on redox potential.

3.1.2.5 Nitrogen

Total inorganic nitrogen (NO_3^- + NO_2^- + NH_4^+ = TIN) is affected by dissolved oxygen concentrations. Nitrification takes place in the

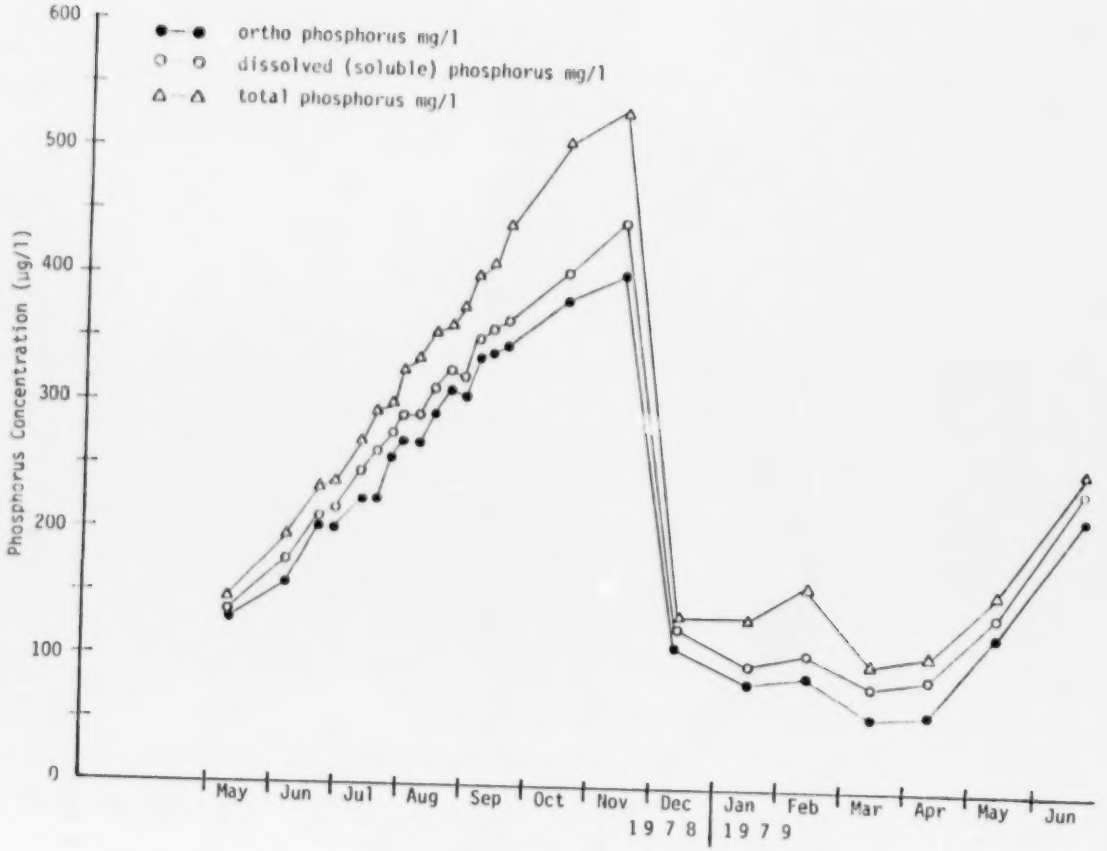

FIGURE 3-8. PHOSPHORUS CONCENTRATIONS IN THE HYPOLIMNION

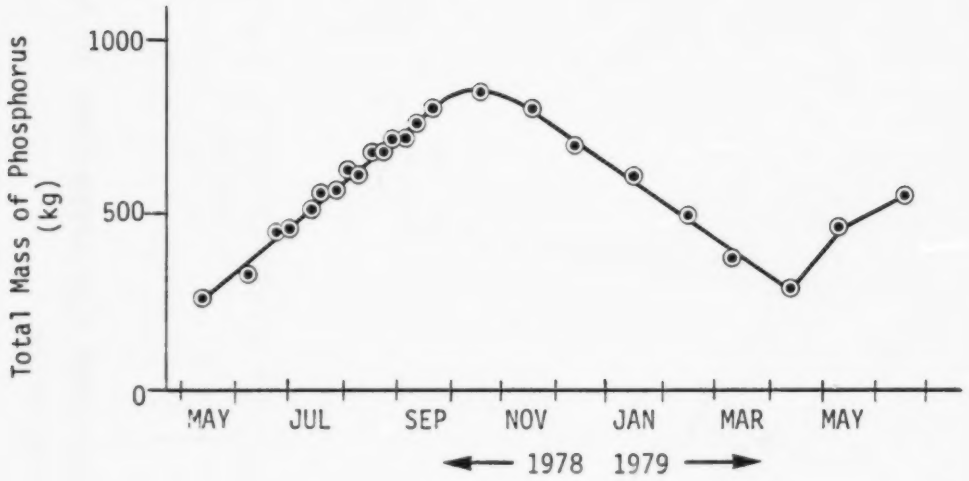

FIGURE 3-9. TOTAL MASS OF PHOSPHORUS IN LAFAYETTE RESERVOIR

Table 3-1

CHEMICAL ANALYSES OF LAFAYETTE RESERVOIR SEDIMENTS
All numbers except for TOC are mg/kg (dry weight).
(Sediment samples collected on 24 October 1978)

	STATION							
	B-1			B-3			B-4	
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-17 cm
Cu	910	610	670	510	250	190	250	120
Fe	35,000	34,000	32,000	30,000	32,000	32,000	20,000	20,000
Al	20,000	21,000	20,000	17,000	20,000	20,000	13,000	13,000
Total Phosphorus	740	730	680	700	640	600	440	410
Acid-extractable Phosphorus	17	19	2.1	28	27	17	<2	<2
Total Organic Carbon (%)	2.63	2.40	2.52	2.00	1.66	1.72	1.35	1.87

presence of oxygen while denitrification occurs in its absence. Ammonification occurs largely in the bottom sediments and assimilation of TIN occurs primarily in the photic zone. These processes affect the composition and quantity of TIN. The pattern of total reservoir mass of TIN varied by a factor of 15 because of these biochemical processes (Figure 3-10). From May 1978 to December 1978 there was a gradual increase of the total mass of TIN in Lafayette Reservoir.

After mixing in November and coinciding with oxygenation of the entire vertical mass of water, TIN begins to decrease, attaining a minimum value in February at the time of maximum dissolved oxygen saturation. During these same two periods, the total mass of total nitrogen (TN) has a gradually decreasing trend (Figure 3-11). Because TN is approximately 90% organic nitrogen forms, the dynamics of TN are unaffected by TIN to a large extent. However, the converse is not true.

An apparent increasing trend in mass of TN began in February. This was marked in May by a great increase in TN and TIN along with the appearance of *Aphanizomenon*, a blue-green alga capable of fixing nitrogen gas. When this alga and similar types are observed, it is normal procedure for the EBMUD to treat Lafayette Reservoir with copper sulfate ($CuSO_4 \cdot 5H_2O$). Copper is toxic to algae at high concentrations ($\sim$300 µg Cu/ℓ) and poisons the nitrogen-fixation enzymes at lower concentrations (5-10 µg Cu/ℓ; Horne and Goldman, 1974). Apparently, the competitive advantage that is conferred on nitrogen fixing algae under conditions of nitrogen limitation would be destroyed by the poisoning.

Apparently, this is what happens in Lafayette Reservoir when the copper sulfate is added to an average concentration of 40 µg Cu/ℓ. Generally heterocysts are common when active nitrogen fixation is occurring in blue-green algae (Horne and Goldman, 1972). However, the N/P ratios

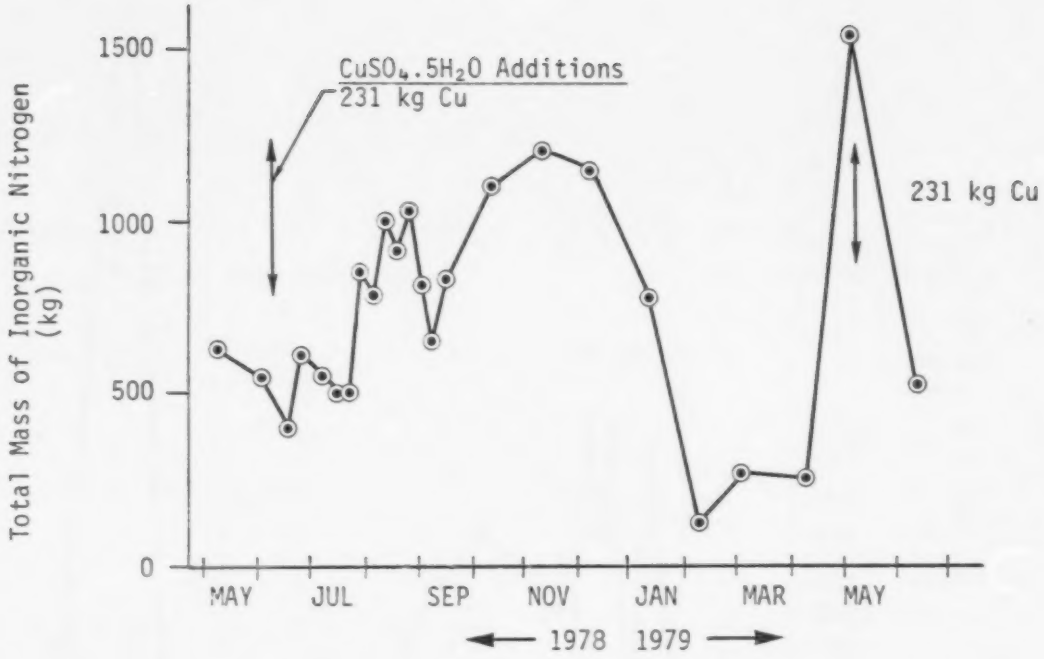

FIGURE 3-10. TOTAL MASS OF INORGANIC NITROGEN IN LAFAYETTE RESERVOIR

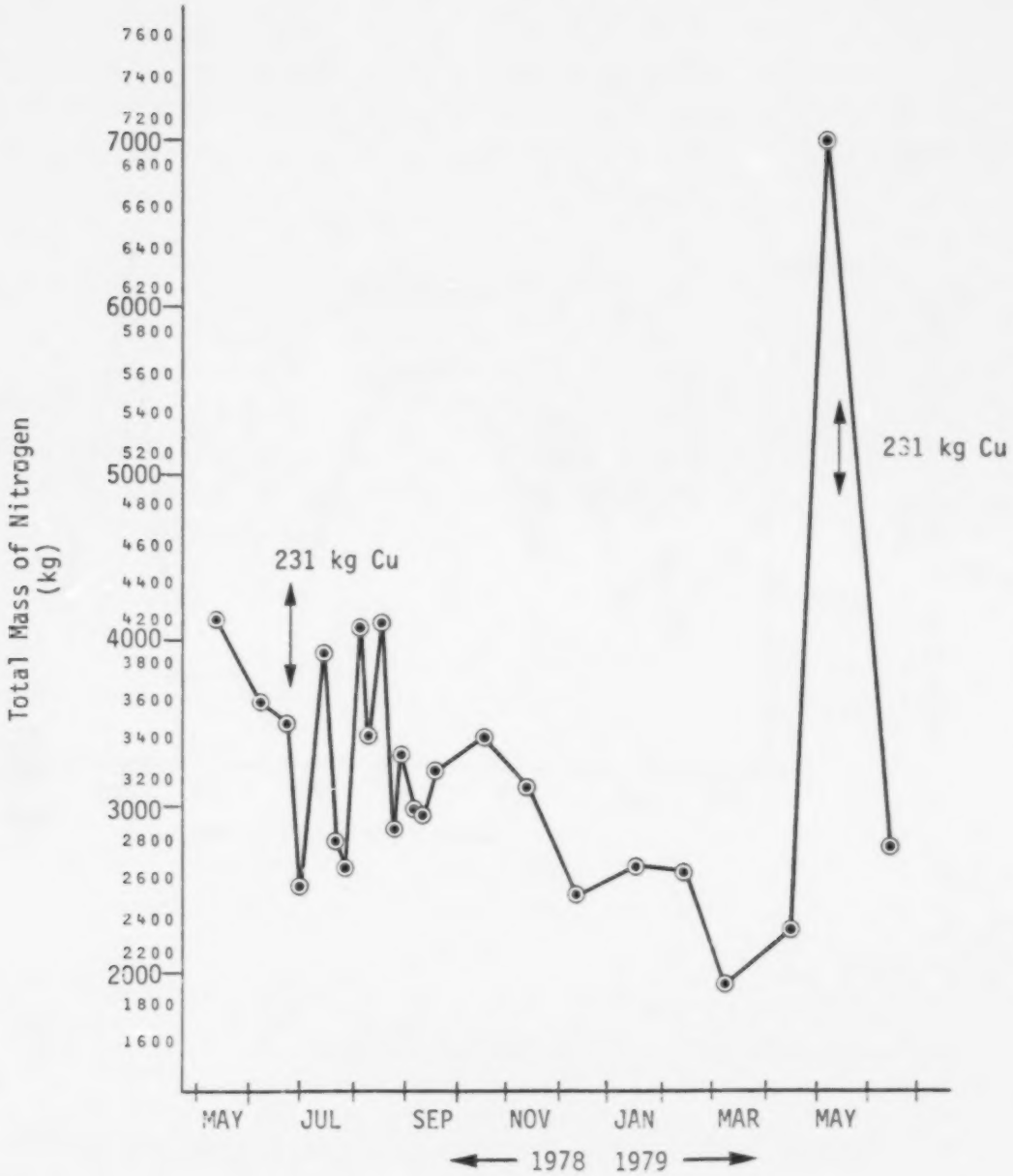

FIGURE 3-11. TOTAL MASS OF NITROGEN IN LAFAYETTE RESERVOIR

in Lafayette Reservoir indicated that nigrogen was limiting (Figure 3-12) throughout the year (N/P < 8) except during periods when *Aphanizomenon* and *Anabaena* were common. In May 1978 and May 1979 these nitrogen fixing algae were common, TN was high, and N/P ratios $\tilde{=}$ 15; when copper was added causing *Aphanizomenon* and *Anabaena* to disappear, the N/P ratio decreased, and TN decreased.

3.1.3 Loadings and Biological Relationships

The hydrologic data for the period 1 July 1978 to 30 June 1979 used to calculate nitrogen and phosphorus relationships in Lafayette Reservoir. Mean concentrations of TN (total nitrogen = NO_3^- + NO_2^- + Kjeldahl N), TIN (= NO_3^- + NO_2^- + NH_4^+) and TP were determined for rainfall based on literature (Likens et al., 1977) measurements for the discharge layer and the arithmetic average of four runoff events for Lafayette Reservoir (Table 3-2).

Watershed yield of TP averaged 1.4 kg/day or 0.41 mg/m^2/day. The mean dissolved phosphorus concentration in runoff samples was 0.068 mg/ℓ. The total dissolved phosphorus production rate was therefore 27.6 g/year, 0.76 g/day or 0.02 mg/m^2/day. Watershed yield of TN averaged 3.8 kg/day or 1.13 mg/m^2/day. The TIN production rate was 0.78 kg/day or 1.13 mg/m^2/day. On an annual basis the watershed production of TP (1.5 kg/ha/yr) and TN (4.1 kg/ha/yr) was up to an order of magnitude greater than levels reported for temperate forested watersheds (Likens et al., 1977).

The higher concentrations of TN and TP recorded in the runoff samples are most likely related to the topography of the land in the catchment basin. The average slope within the basin is approximately 20%; infiltration rates of the soils are low; and the watershed is characterized by numerous small, intermittent creeks in highly-eroded gullies rather than well-defined stream channels. Thus, runoff velocities as well as the sediment loads of the surface drainage are high (suspended

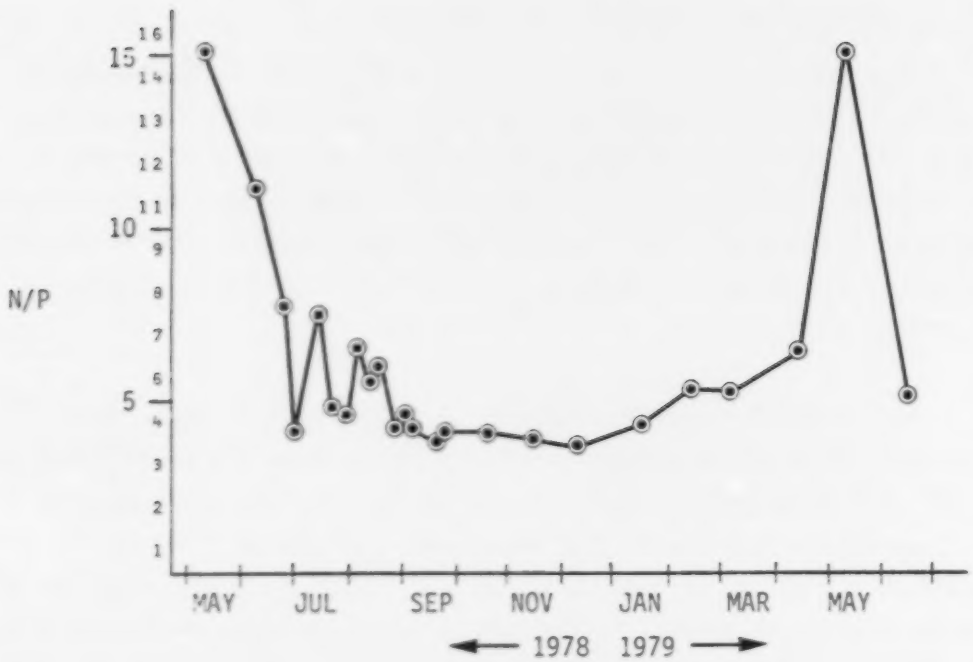

FIGURE 3-12. TOTAL NITROGEN TO TOTAL PHOSPHORUS RATIOS IN LAFAYETTE RESERVOIR

Table 3-2

NITROGEN AND PHOSPHORUS MASS FLOWS INTO LAFAYETTE RESERVOIR

Source*	Mean Concentration, mg/ℓ			Mean Load m^3/yr	Mass kg/yr		
	TP	TIN	TN		TP	TIN	TN
Rainfall	0.008	1.69	2.11	312,350	2.5	528	650
Runoff	1.24	0.704	3.41	406,100	502	286	139
Discharge	0.075	0.184	0.955	67,400	5.5	12	64
Net kg/yr					500	800	200
Loading $mg/m^2/day$					2.46	3.94	9.86

*Rainfall from Likens et al., 1977; others measured at Lafayette Reservoir. Discharge based on appropriate surface samples because it is overflow.

solids concentration of the runoff samples averaged 0.86 g/ℓ and ranged from 0.01 to 7.3 g/ℓ). These characteristics result in high particulate phosphorus concentrations and a concomitantly high TP production rate. While the production of TP in the watershed was up to an order of magnitude higher than reported levels of production in forested watersheds, the watershed production rate of orthophosphate was approximately equal to levels reported in the literature (0.05 kg/ha/yr, Uttormark, 1974).

Loading values to the lake were calculated using the various equations for relating eutrophication levels of lakes to total phosphorus (0.9 $gP/m^2/yr$) and showed that Lafayette Reservoir was within the eutrophic range (reviewed in Hern et al., 1980). There is so little discharge from Lafayette Reservoir that essentially all of the input nutrients are retained (99% of TP; 97% of TN). Attempts to calculate a steady state TP concentration approximating measured concentrations (for example, using the relationship of Jones and Bachmann, 1976) failed. The mean concentration of epilimnetic TP in Lafayette Reservoir (0.75 mg P/ℓ) was used to calculate steady state chlorophyll-a concentration. This provided values, depending on the equation used (reviewed in Hern et al., 1980), ranging from 12-44 µg chlorophyll-a/ℓ. This range contains the average July-August concentration of epilimnetic (top 10 m) chlorophyll-a (15.1 mg/m^3) in Lafayette Reservoir (Figure 3-13).

The relationship between light and photosynthesis requires that light be adequate to utilize available nutrients in growth of phytoplankton. Secchi disc measurements have been used to assess the relative limitation of light and nutrients (Lorenzen, 1978). The temporal pattern of Secchi depth (Figure 3-14) and chlorophyll-a (Figure 3-13) indicate that these variables behave reciprocally. Lorenzen, 1978 defined a relationship between Secchi depth (SD) and chlorophyll-a (CA) based on the Beer-Lambert law:

$$SD = \frac{1.61}{\alpha + \beta\ CA} \qquad \text{or} \qquad \frac{1.61}{SD} = \alpha + \beta\ CA$$

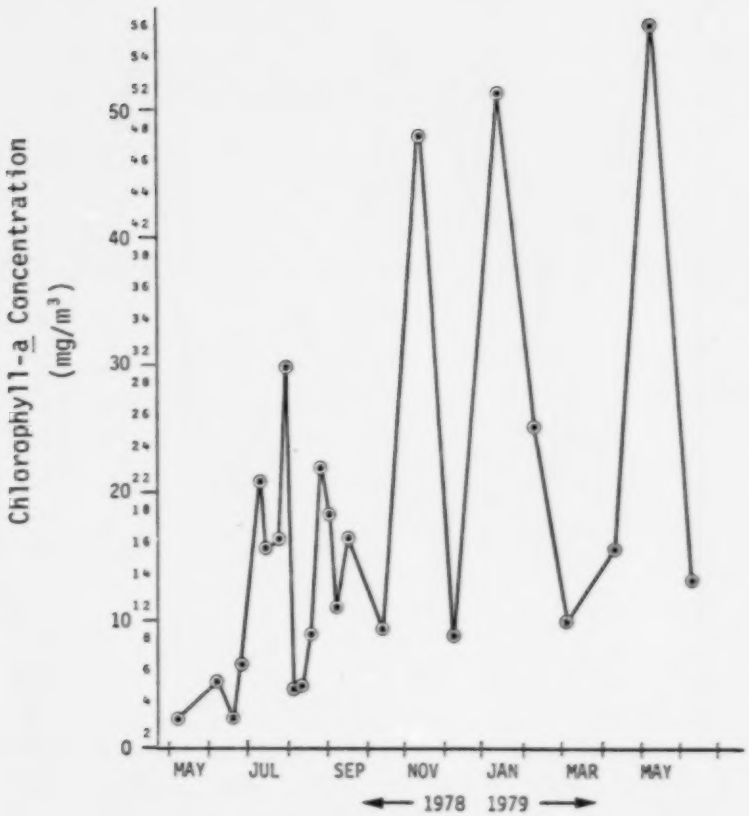

FIGURE 3-13. CONCENTRATION OF CHLOROPHYLL-A IN THE EPILIMNION OF LAFAYETTE RESERVOIR

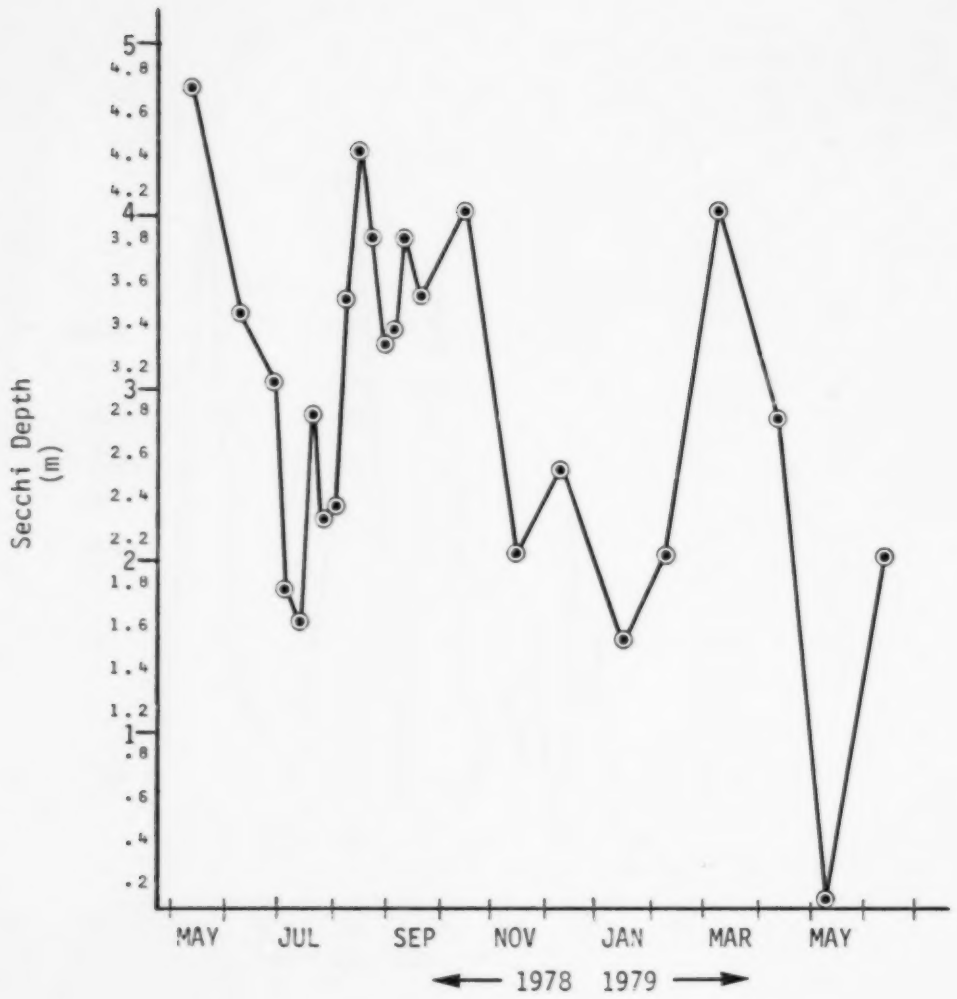

FIGURE 3-14. SECCHI DEPTH MEASUREMENTS AT LAFAYETTE RESERVOIR

The value of α is related to light absorption by non-chlorophyll-a materials (water, clay particles, organic and inorganic compounds) and β is the chlorophyll-a light absorption coefficient. In Lafayette Reservoir the relationship was found to be:

$$\frac{1}{SD} = 0.134 + 1.1587\ CA$$

with a correlation coefficient of 0.73. Assuming that SD is attained at 20% light penetration (Lorenzen, 1978), extinction due to chlorophyll-a would be 0.036. The coefficient for photosynthetically active light generally is in the range of 0.015 to .022 mgC/m^2 (Megard, 1980). However, conversion of Secchi disc disappearance to extinction coefficients, differences in algal communities, and the depth over which chlorophyll-a is averaged, may have been responsible for the observed values.

3.2 PHYTOPLANKTON

3.2.1 Chlorophyll-a Concentrations

Chlorophyll-a concentrations measured at the surface were relatively constant during the initial phase of the sampling period, but showed a marked increase coinciding with the mixing of the reservoir. Surface chlorophyll-a concentrations varied from 1.6-4.9 mg/m^3 during the period of 18 July-17 October (Table 3-3 and Figure 3-15). Substantially higher concentrations of the photosynthetic pigment were measured in the surface waters on the 14 November and 16 January sampling dates. These increased concentrations of chlorophyll-a, 11.0 and 13.0 mg/m^3 respectively, mirror the release of nutrients to the epilimnion with reservoir mixing. Chlorophyll-a concentrations measured at the surface during the period 13 February-17 April 1979 were again relatively constant and ranged from 3.6-6.7 mg/m^3. The highest concentration of photosynthetic pigments near the surface was measured near

Table 3-3

CHLOROPHYLL-a CONCENTRATIONS (mg/m^3)
AT LAFAYETTE RESERVOIR

Date	DEPTH (M)				
	0.5	6	8	12	18
7/18	2.1	2.6	8.9	3.6	1.2
7/25	1.8	7.9	1.7	0.4	0.3
8/1	4.9	5.7	11.8	1.7	0.8
8/8	1.8	0.9	0.0	1.4	0.6
8/15	1.6	0.8	<0.1*	5.5	0.1
8/22	3.1	2.2	<0.1*	2.1	0.0
8/29	2.5	8.4	3.1	7.0	0.2
9/5	2.1	3.8	10.3	3.4	0.7
9/12	2.0	2.4	4.9	1.5	<0.1
9/19	2.2	2.6	11.0	<0.1*	<0.1*
10/17	2.1	2.6	1.8	<0.1*	<0.1*
11/14	11.0	12.2	12.0	<0.1*	<0.1*
12/12	1.9	1.9	2.6	2.6	1.7
1/16	13.0	12.3	11.2	7.4	7.9
2/13	5.6	6.3	5.8	4.5	6.2
3/13	3.6	1.9	1.2	<0.1	<0.1
4/17	6.7	1.8	2.4	1.1	0.8
5/14	44.3	2.6	3.4	2.2	2.0
6/20	3.0	4.6	0.5	<0.1	.7

*Samples with high phaeophytin-a concentrations can show negative chlorophyll-a values because of variance.

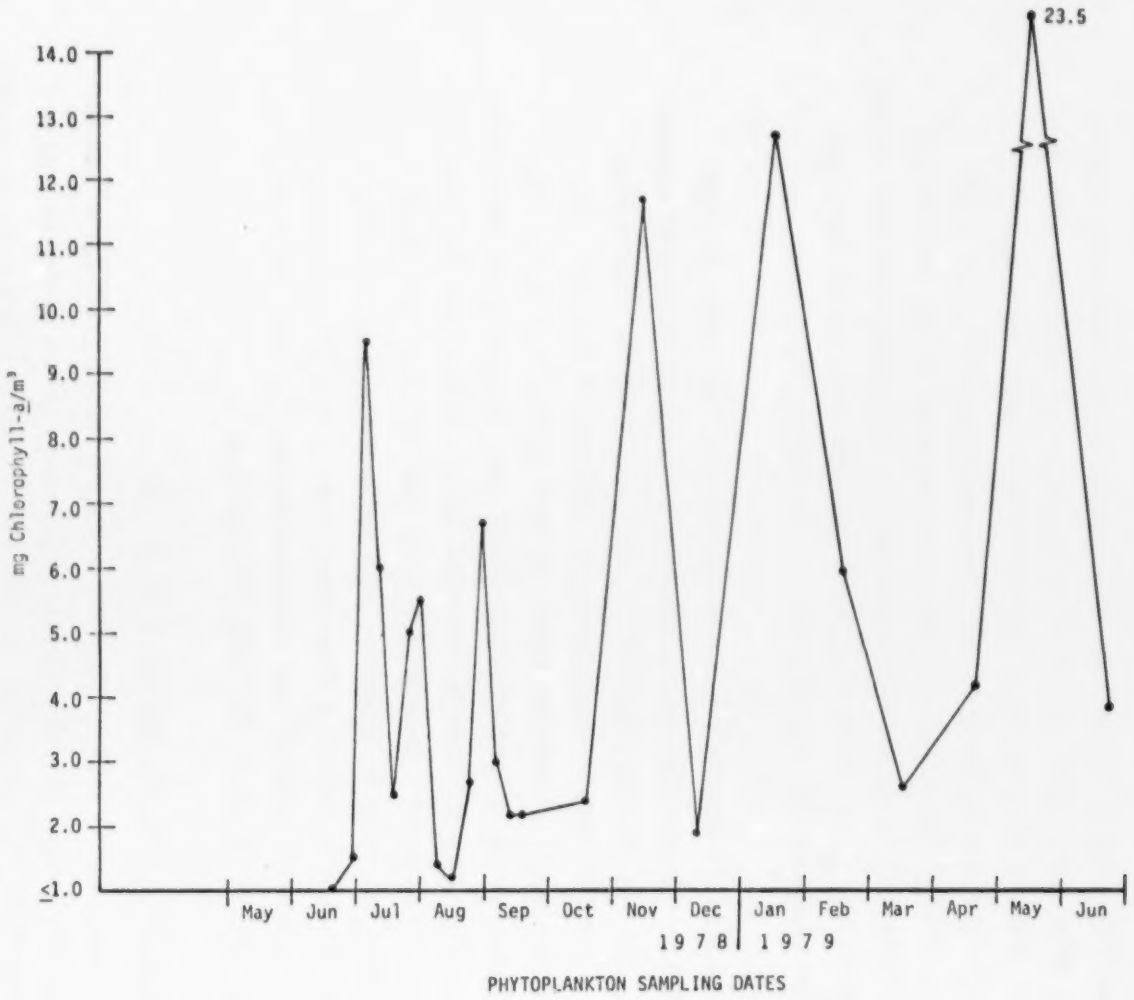

FIGURE 3-15. MEAN CHLOROPHYLL-A CONCENTRATIONS MEASURED AT THE SURFACE AND 6.0 M DURING THE PERIOD 23 JUNE 1978--20 JUNE 1979

the conclusion of the sampling program during a blue-green algal bloom (44.3 mg/m^3 at 0.5 m on 14 May 1979).

Generally higher, as well as more variable, chlorophyll-a concentrations were measured in the metalimnion prior to reservoir mixing in the fall. During the period 18 July-17 October 1978 the range of chlorophyll-a concentrations in the metalimnion was 0.0-11.8 mg/m^3. Similar chlorophyll-a concentrations were measured in the metalimnion and epilimnion for a period of several months following reservoir mixing, but higher pigment concentrations were measured near the surface each month from 13 March 1979 through the conclusion of the study.

Calculated chlorophyll-a concentrations for the upper 10 m of Lafayette Reservoir, based on volumetrically weighted values of concentrations measured during the study period, are shown in Figure 3-16. The mean concentration of photosynthetic pigments in the epi- and metalimnetic waters generally ranged between 1.0 and 7.0 mg/m^3, but during phytoplankton blooms markedly higher chlorophyll-a pigments were measured. On sampling dates in November 1978, January and May 1979, mean concentrations of chlorophyll-a were greater than 11.0 mg/m^3. Diatom blooms occurred in November 1978 following the fall overturn and again in January 1979. A blue-green algal bloom, which was essentially a surface phenomenon, was responsible for the high chlorophyll-a concentrations observed in May 1979 (Figure 3-16).

3.2.2 Cell Densities and Species Composition

The mean number of phytoplankton cells in the 0.5 and 5.0 m samples as well as the number of cells in the 9.5 m samples are shown in Figure 3-17. Only the 9.5 m samples collected from May through December 1978 were examined and enumerated. During this period, concentrations of cells peaked in August and exceeded 1.0×10^7 cells/ℓ from July through October; these samples were composed almost exclusively of the blue-green alga *Merismopedia*. The samples collected in November and

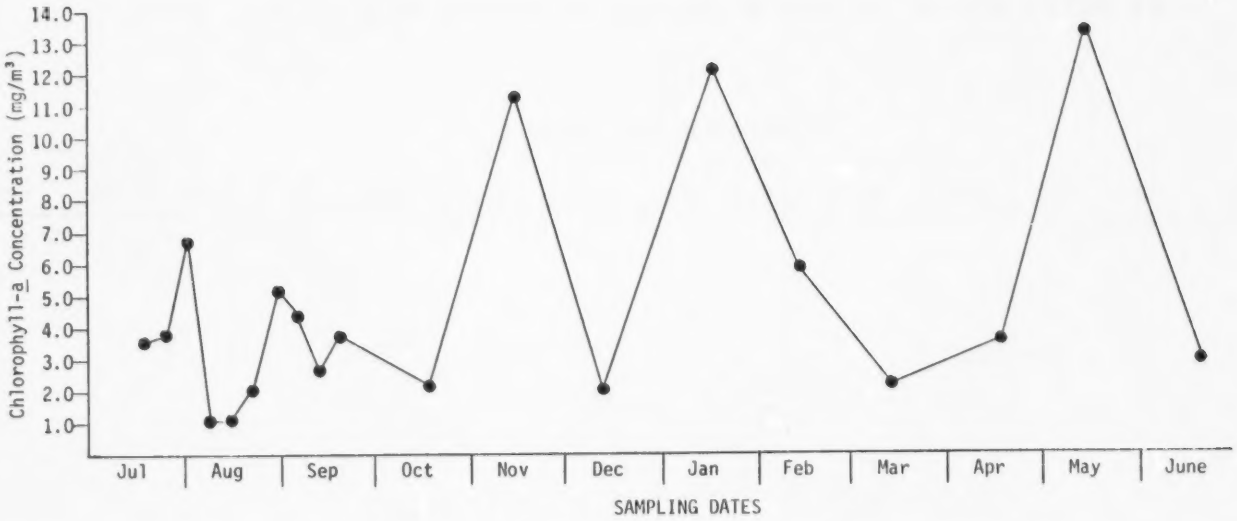

FIGURE 3-16. VOLUMETRICALLY WEIGHTED MEAN CONCENTRATIONS OF CHLOROPHYLL-A IN THE UPPER 10 M OF LAFAYETTE RESERVOIR

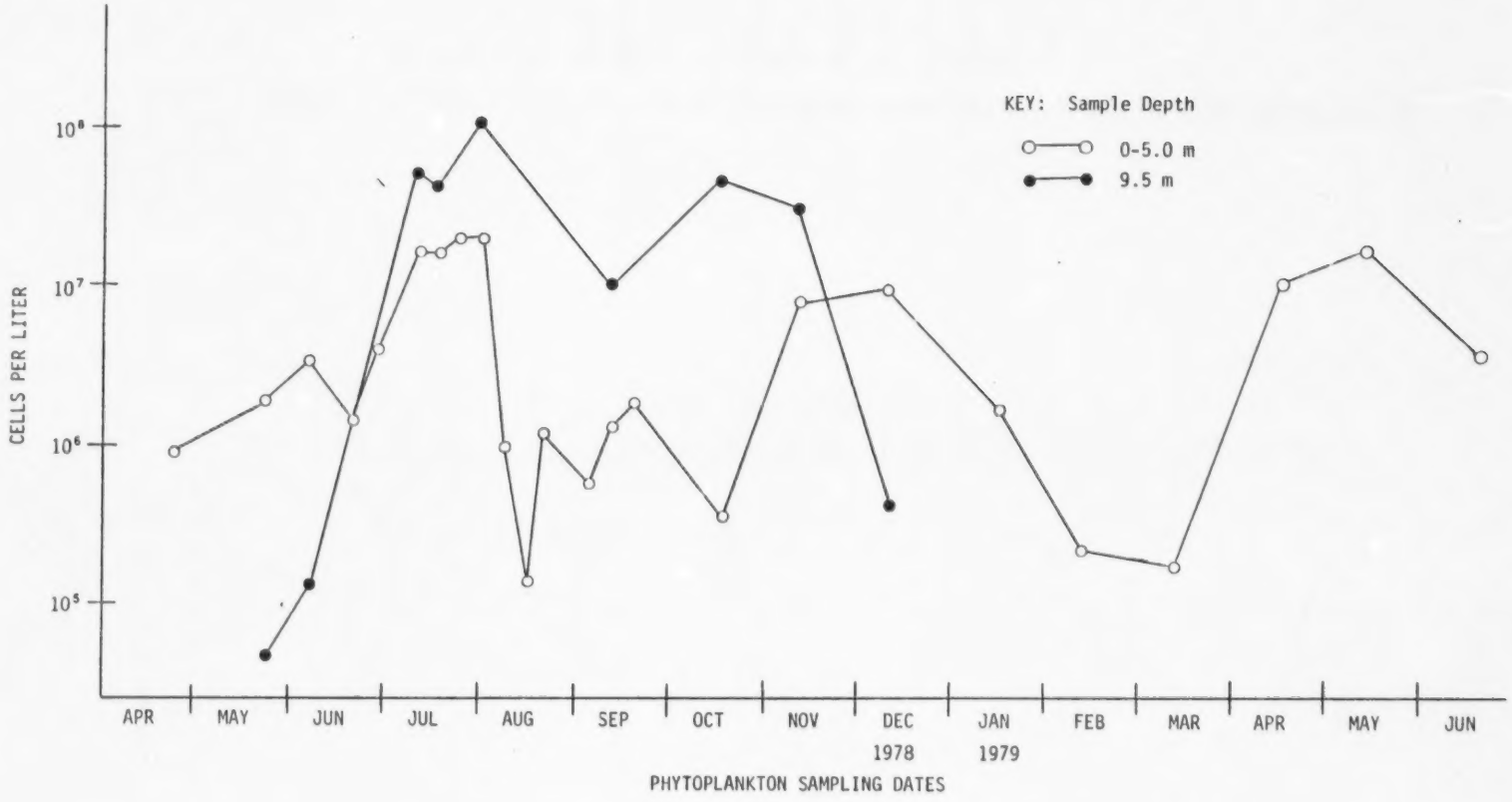

FIGURE 3-17. MEAN NUMBER OF PHYTOPLANKTON CELLS PER LITER IN THE EPILIMNION AND METALIMNION

December were dominated by the diatoms *Fragilaria crotonensis* and *Asterionella formosa*.

The mean density of phytoplankton in the epilimnion ranged from a low of 2.1 x 10^5 cells/ℓ on 13 February 1979 to a maximum of 1.2 x 10^8 cells/ℓ on 14 May 1979. During this period of study, three large peaks in phytoplankton cell densities were observed (Figure 3-17). In July and early August 1978 the density of epilimnion phytoplankton samples, which were composed primarily of the blue-green algae *Anabaena catenula* and *A. spiroides*, exceeded 1.0 x 10^7 cells/ℓ. Diatoms, *Fragilaria crotonensis* and *Asterionella formosa*, and unidentified flagellates dominated the samples during another peak recorded during November and December 1978. A third peak in phytoplankton densities occurred during the period April through June 1979. The blue-green algae *Anabaena catenula* and *A. spiroides* dominated the April samples, and these were succeeded by the blue-green alga *Aphanizomenon* in May. However, following treatment of the reservoir on 14 May with copper sulfate, green algae, primarily *Oocystis* and *Elaktothrix*, dominated the samples collected in June.

Small unidentified flagellates were abundant in almost all the samples collected. Together, these unidentified flagellates and the flagellate *Cryptomonas* accounted for the majority of cells in 25% of the samples collected at 0.5 and 5.0 m. The density of these cells was greatest in December 1978 (9.0 x 10^5 cells/ℓ) and accounted for 98% of the total cell density.

A comprehensive list of phytoplankton taxa identified from samples collected during this study is provided in Table 3-4. Dominant phytoplankton taxa, i.e., those which either consistently occurred in relatively high densities in near surface or metalimnion samples or were associated with bloom phenomena are listed in Table 3-5. The diatoms included in this list, *Fragilaria crotonensis* and *Asterionella formosa*, for example, were present in almost all the samples collected from the

Table 3-4

COMPREHENSIVE LIST OF PHYTOPLANKTON TAXA IDENTIFIED FROM SAMPLES COLLECTED DURING THIS STUDY

Myxophyceae

Anabaena sp.
Anabaena catenula
Anabaena spiroides
Microcystis
Merismopedia
Oscillatoria
Aphanizomenon
Raphidiopsis
Chroococcus

Chlorophyceae

Gloeocystis
Ankistrodesmus
Schroderia
Elaktothrix
Coelastrum
Staurastrum
Chlamydomonas
Oocystis
Scenedesmus
Ulothrix
Eudorina
Pediastrum
Cosmarium
Tetraedron
Dictyosphaerium
Botryococcus

Bacillariophyceae

Achnanthes lanceolata
Asterionella formosa
Fragilaria crotonensis
F. construens
Navicula
Nitzschia acicularis
Melosira granulata
Rhopalodia gibba
Synedra sp.
Synedra ulna
Synedra acus
Stephanodiscus astraea
S. niagarae

Chrysophyceae

Mallomonas
Dinobryon
Hyalobryon

Dinophyceae

Ceratium hirudinella
Gymnodinium

Cryptophyceae

Cryptomonas

Euglenophyceae

Trachelomonas
Euglena

Table 3-5

DOMINANT PHYTOPLANKTON TAXA OCCURRING IN LAFAYETTE RESERVOIR DURING THE PERIOD 25 APRIL 1978 - 20 JUNE 1979

Diatoms	Blue-greens
Fragilaria crotonensis	*Anabaena spiroides*
Asterionella formosa	*A. catenula*
	Aphanizomenon flos-aquae
Greens	*Merismopedia*
Schroderia sp.	
Oocystis	Other
Chlamydomonas	*Cryptomonas*
Gloeocystis	

upper 5.0 m of the reservoir. In addition, these species dominated samples in which diatoms accounted for greater than 50% of the total cell density. The solitary green algae *Schroderia* and *Chlamydomonas*, likewise, were encountered in most of the samples examined. *Oocystis* and *Gloeocystis*, which occurred in small clusters or colonies, were not as consistently encountered as the other green algae, but they frequently occurred in relatively high densities. *Gloeocystis* and *Oocystis* were the most abundant algae in the surface samples and most of the 5.0 m samples during the period 22 August-19 September 1978. Maximum densities of *Gloeocystis* during this period, for example, were 6.5×10^5 colonies/ℓ. The filamentous, gas vacuolate blue-green algae *Anabaena spiroides* and *A. catenula* were present in most of the surface samples, and, as noted above, dominated samples collected in May and July 1978 as well as those collected in April 1979. The filamentous blue-green alga *Aphanizomenon flos-aquae* was abundant only in samples collected on a single date (14 May 1979), but densities of this species exceeded 1.2×10^8 cells/ℓ during the observed bloom. Unfortunately, careful counts of heterocysts (>3 per 1000 cells indicates nitrogen fixation; Horne and Goldman, 1972) were not made. The remaining dominant blue-green taxon, *Merismopedia*, was the most abundant algae in the metalimnion samples during the period June through October 1978. The maximum recorded cell density of this non-gas vacuolate alga, which forms many-celled free floating colonies, was 1.02×10^7 colonies/ℓ. As noted above, unicellular motile algae of the genus *Cryptomonas* were abundant in samples from near the surface as well as deeper water samples throughout the period of study.

The relative importance of the major groups of phytoplankton (excluding small flagellates and *Cryptomonas*) expressed in terms of cell densities in surface and metalimnion samples is depicted in Figure 3-18 and 3-19. As indicated in Figure 3-18, green algae densities at the surface were comparatively high on several occasions. The maximum green algal density measured in the surface waters during the study was approximately 1.5×10^6 cells/ℓ (June 1979). However, much lower densities of

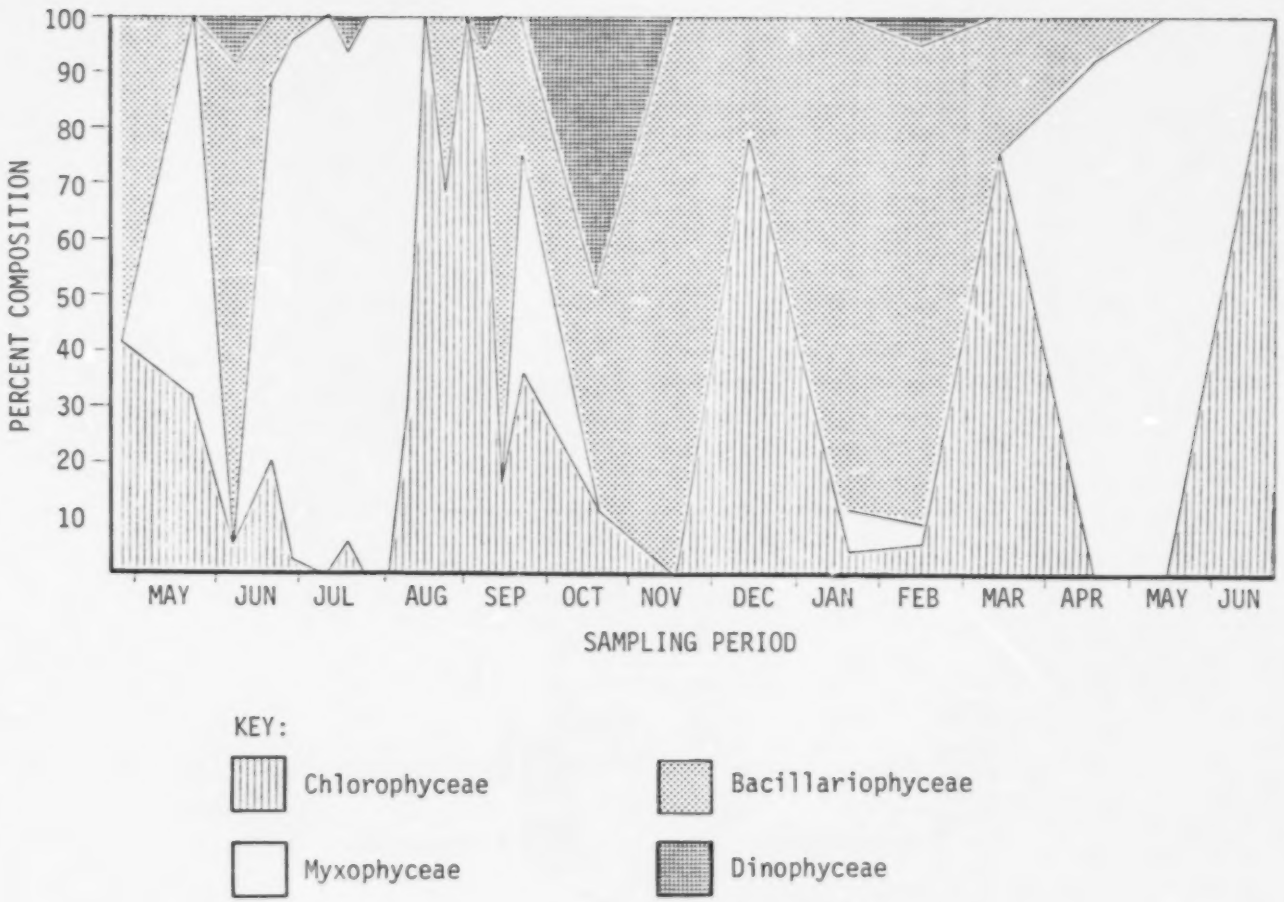

FIGURE 3-18. PERCENT COMPOSITION OF MAJOR PHYTOPLANKTON GROUPS IN SAMPLES COLLECTED AT THE SURFACE DURING THE PERIOD 25 APRIL 1978-20 JUNE 1979

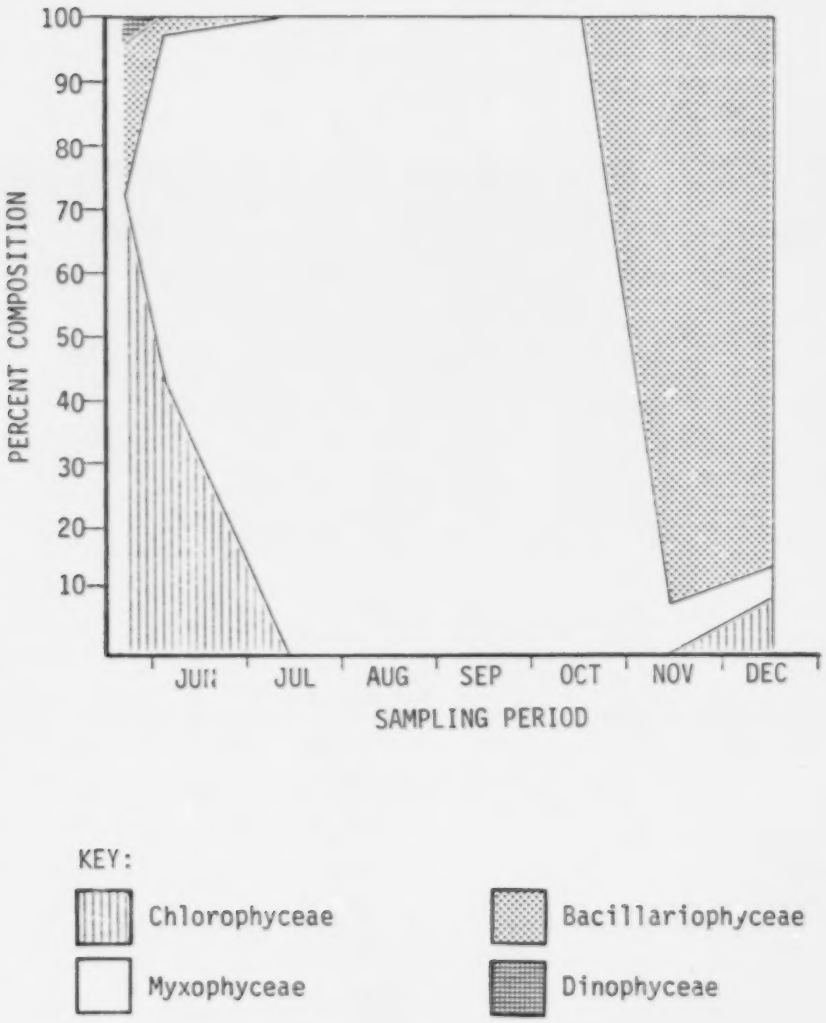

FIGURE 3-19. PERCENT COMPOSITION OF MAJOR PHYTOPLANKTON GROUPS IN SAMPLES COLLECTED IN THE METALIMNION DURING THE PERIOD 23 MAY-12 DECEMBER 1978

green algae (1.3×10^4 to 7.3×10^5 cells/ℓ) were recorded during other periods when they represented the major component of this portion of the enumerated organisms. Diatoms dominated the surface samples collected in November 1978 following mixing of the reservoir as well as samples collected in January and February 1979; diatom densities exceeding 6.5×10^6, 4.4×10^6 and 1.7×10^5 cells/ℓ were recorded from the November, January and February samples, respectively. Blue-green algae dominated this component of the surface samples in May 1978 and throughout July 1978 during which time maximum densities of 2.0×10^7 cells/ℓ were recorded. Blue-greens again dominated the samples in April and May 1979 when, as previously noted, high densities of *Aphanizomenon* were recorded. Dinoflagellates, *Gymnodinium* and *Ceratium*, dominated the surface samples on 12 October 1978 during a period when the overall density of phytoplankton cells was relatively low; dinoflagellate abundances were approximately 4.0×10^4 cells/ℓ on this date.

As shown in Figure 3-19 the samples collected from the metalimnion during June through October were dominated by the Myxophyceae. During the midsummer period blue-green algae accounted for 99.9% of the algal cells counted in these samples. Although other genera were represented in these samples, *Merismopedia* spp. was clearly the most abundant algal taxa; densities exceeding 6.00×10^8 cells/ℓ were recorded for these species on 1 August. Diatoms were the dominant algae in the metalimnion samples during November and December 1978. This period coincides with the mixing of the reservoir, and the densities of diatoms were high in samples from throughout the water column.

The abundances of green and blue-green algae, diatoms and dinoflagellates in samples collected near the surface and 9.5 m between 25 April 1978 and 20 June 1979 are depicted in Figures 3-20 and 3-21, respectively. Additionally, the collective abundances of small unidentified flagellates, cryptomonads *(Cryptomonas)* and chrysomonads *(Dinobryon* and *Hyalobryon)* in surface samples are indicated in Figure 3-20. Because of potential

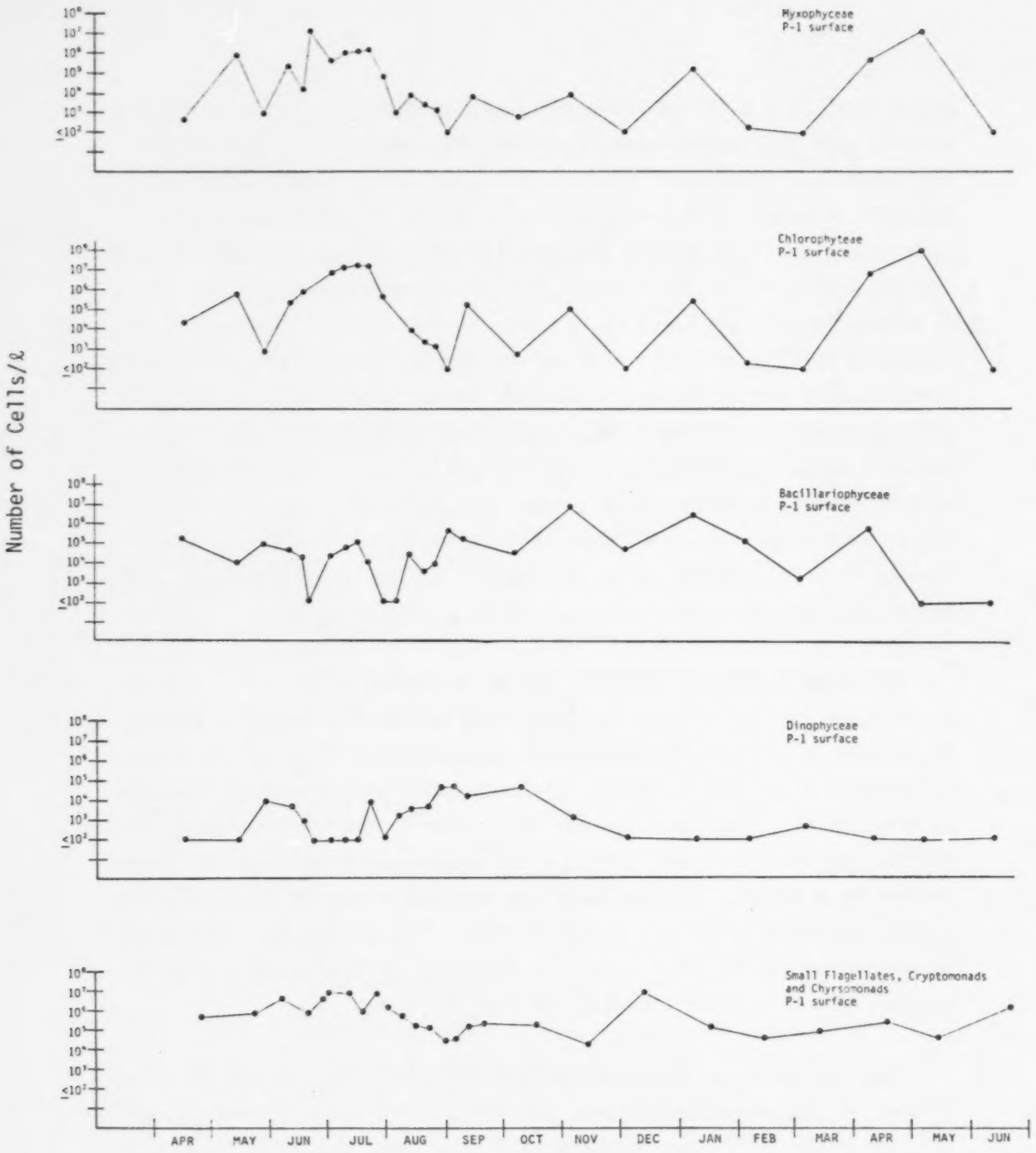

FIGURE 3-20. ABUNDANCES OF PHYTOPLANKTON GROUPS OBSERVED IN SURFACE SAMPLES COLLECTED DURING THE PERIOD 25 APRIL 1978 - 20 JUNE 1979

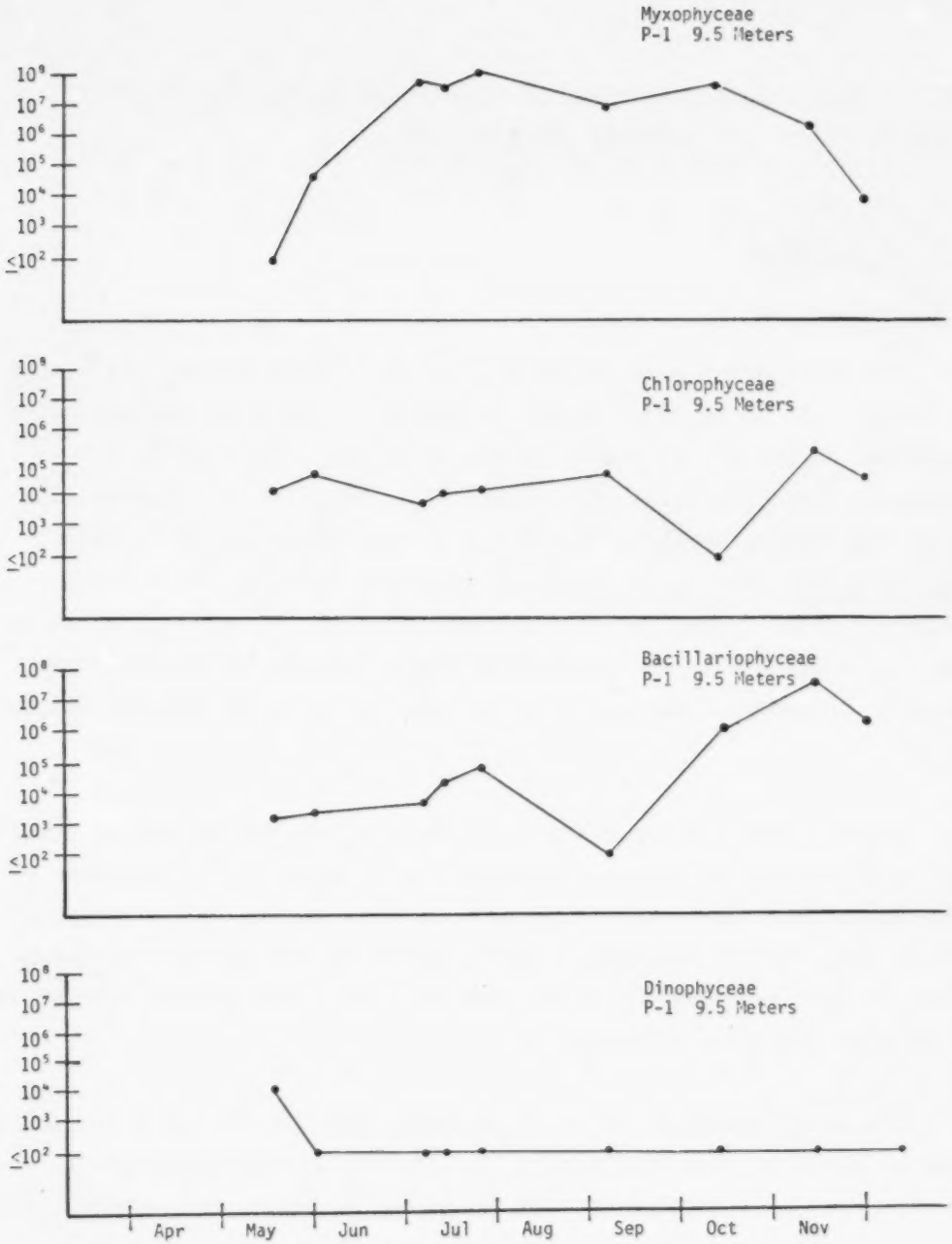

FIGURE 3-21. ABUNDANCES OF MAJOR PHYTOPLANKTON GROUPS OBSERVED IN 9.5 M SAMPLES COLLECTED DURING THE PERIOD 25 APRIL 1978 - 20 JUNE 1979

cell disruption and distortion of flagellates during preservation, these estimates are probably conservative.

3.3 ZOOPLANKTON

3.3.1 Abundance

The zooplankton taxa collected during the study period are listed in Table 3-6. Three major groups (copepods, cladocerans and rotifers) comprised almost all of the organisms collected. An occasional *Chaoborus* larva (Insecta: Culicidae) was also observed; however, the collected numbers were not considered to be representative of actual chaoborid densities due to the pump avoidance ability of the free-swimming larvae. They are also primarily benthic or epibenthic during the day and would not be susceptible to zooplankton collection techniques. Therefore, *Chaoborus* will be considered in the benthos section (3.4).

Highest zooplankton densities (100-200/ℓ) in the epilimnion occurred during the period of February through June (Figure 3-22). Maximum crustacean zooplankton densities were observed during February through April, with overall abundances declining during the spring and summer. There is also evidence for a less distinct fall peak in both copepod and cladoceran densities (Figure 3-22).

The mean abundances of major copepod groups in the 0.5 m and 5.0 m samples are presented in Figure 3-23. The filter-feeding calanoid copepod *Diaptomus* reached maximum densities in August and November, with numbers declining to very low levels in the spring. This period of decline in calanoid copepods corresponds with the maximum densities of the mainly predatory cyclopoid copepods. Densities of *Cyclops* and *Mesocyclops* exceeded 50/ℓ during February and March. *Daphnia* displayed two periods of seasonal maxima during late summer and late winter-early spring (Figure 3-24). The smaller cladoceran *Bosmina* was essentially

Table 3-6

MICROCRUSTACEAN TAXA OBSERVED IN LAFAYETTE RESERVOIR SAMPLES

COPEPODS

Suborder Cyclopoida

Mesocyclops sp.

Cyclops spp.

Suborder Calanoida

Diaptomus sp.

CLADOCERANS

Daphnia (pulex ?)

Daphnia ambigua

Bosmina sp.

Allonella sp.

Diaphanosoma leuchtenbergianum

ROTIFERS

Family Asplanchnidae

Asplanchna sp.

Family Brachionidae

Keratella cochlearis

Keratella quadrata

Family Synchaetidae

Polyarthra sp.

Family Gastropodidae

INSECTS

Family Culicidae

Chaoborus sp.

FIGURE 3-22. EPILIMNETIC ZOOPLANKTON DENSITIES IN LAFAYETTE RESERVOIR DURING THE PERIOD JUNE 1978--JUNE 1979

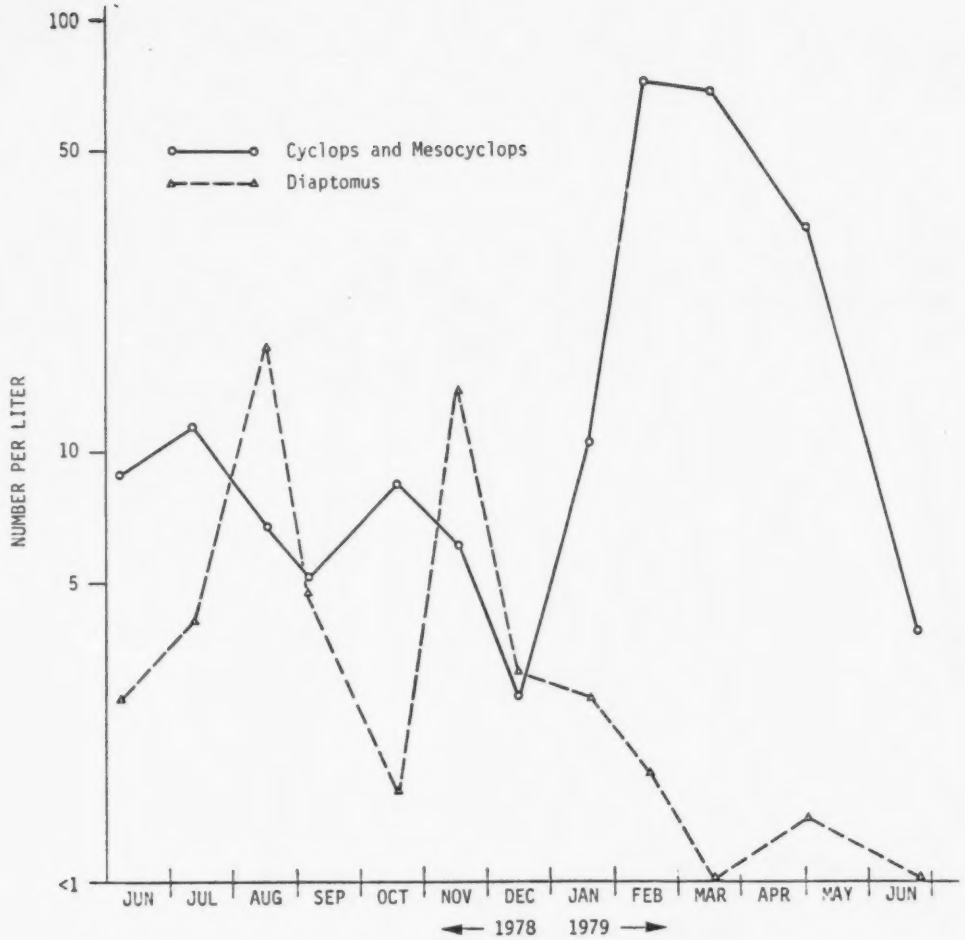

FIGURE 3-23. THE MEAN ABUNDANCES OF MAJOR COPEPOD GROUPS IN THE 0.5 M AND 5.0 M ZOOPLANKTON SAMPLES

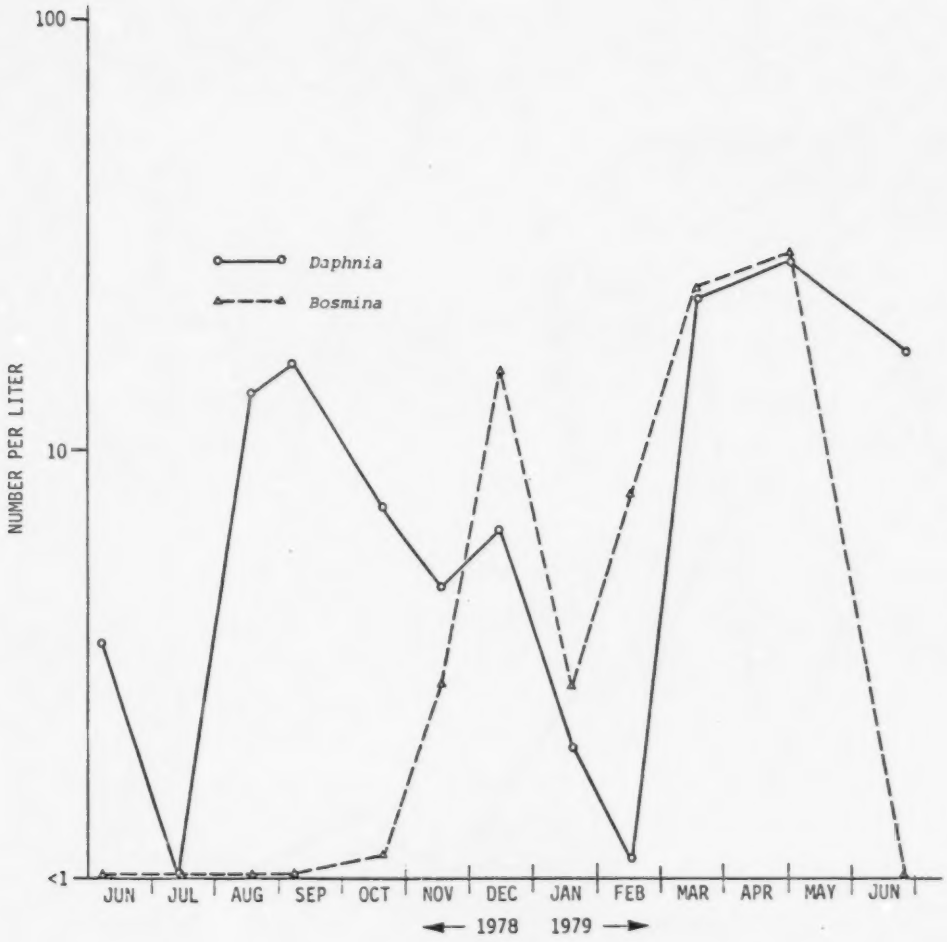

FIGURE 3-24. THE MEAN ABUNDANCES OF MAJOR CLADOCERAN GROUPS IN THE 0.5 M AND 5.0 M IN ZOOPLANKTON SAMPLES

absent during the summer and co-occurred with *Daphnia* at approximately equal densities during fall and winter.

The seasonal composition of the crustacean zooplankton community is diagrammed in Figure 3-25. The predatory copepods *Cyclops* and *Mesocyclops* dominated these communities (as percent occurrence) during early summer (June and July) and again in winter. Although the predatory copepods comprised approximately 60-75% of the crustacean zooplankton in June-July, the actual organism densities were at moderate levels (~10/ℓ). Their high percentage dominance of the communities was due to the corresponding low occurrence of cladocerans at that time.

The February peak in percent occurrence corresponded with the numerical abundance peak of cyclopoids; however, the late winter-early spring increase in cladocerans resulted in a declining proportional occurrence of cyclopoids.

Four families of Rotifera occurred planktonically in Lafayette Reservoir: Gastropodidae, Synchaetidae, Asplanchnidae and Brachionidae. The rotifers displayed distinct seasonal abundance fluctuations that were characteristic of the individual families; however, total rotifer abundances were less variable and remained relatively low from June through January. During this period total rotifer densities ranged from approximately 1 to 24 organisms/ℓ, with lowest densities occurring in midsummer. Peak rotifer densities were observed in midwinter (151 organisms/ℓ) and again in the spring (64-139 organisms/ℓ).

The common planktonic rotifer family Brachionidae was the only group collected year-round at Lafayette Reservoir. There were two distinct population peaks in the late fall and spring (Figure 3-26). The predaceous asplanchnids were very rare or absent from plankton samples collected from June through September (Figure 3-26). Peak densities occurred during February, which corresponded with the highest abundances of predaceous cyclopoid copepods.

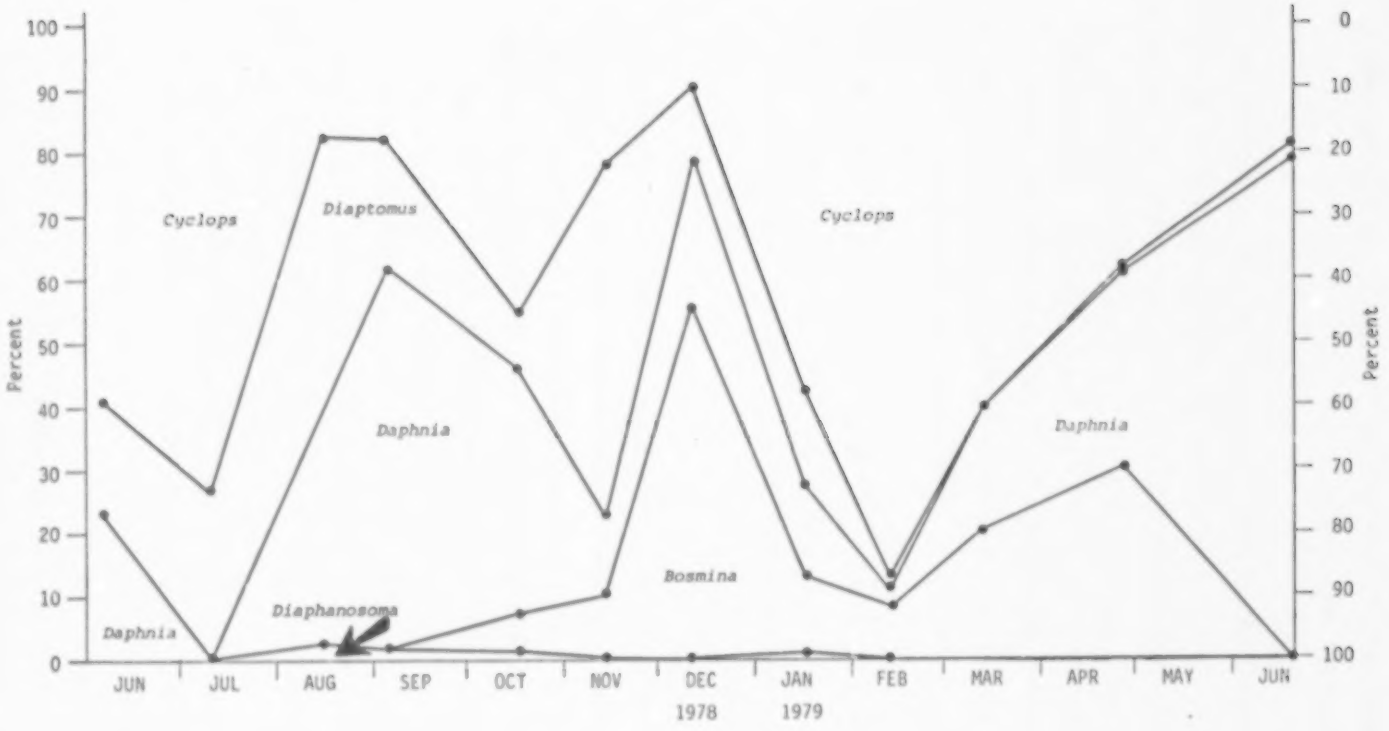

FIGURE 3-25. SEASONAL COMPOSITION OF THE CRUSTACEAN ZOOPLANKTON COMMUNITY

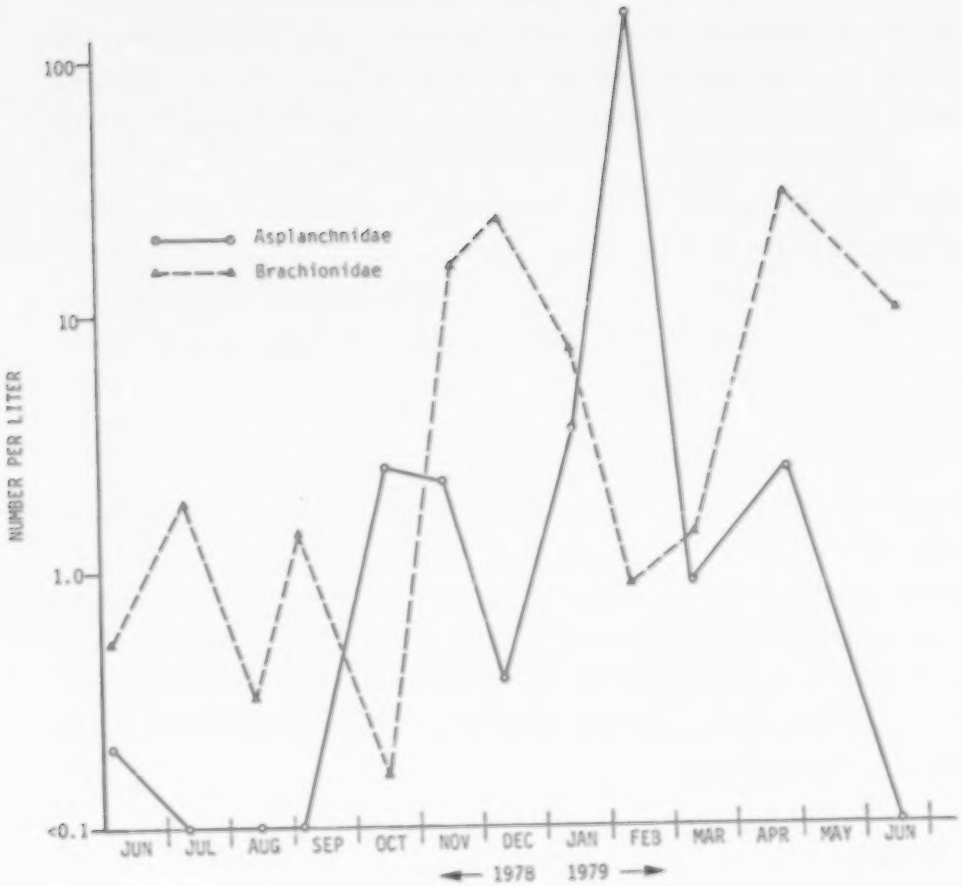

FIGURE 3-26. MEAN ABUNDANCES OF ASPLANCHNID AND BRACHIONID ROTIFERS IN THE 0.5 M AND 5.0 M ZOOPLANKTON SAMPLES

The synchaetids and gastropodids were characteristically absent from the winter plankton samples (Figure 3-27). The gastropodids displayed a very pronounced population increase in the spring (>100/ℓ), followed by a general decline throughout the summer and fall. The synchaetid rotifers *Polyarthra* spp. displayed a bimodal density distribution with peaks occurring in the spring and fall (Figure 3-27). Many species of *Polyarthra* typically have either spring or fall abundance maxima. The occurrence of two peaks in Lafayette Reservoir probably represents at least two distinct species with different temperature-dependent population trends.

The gastropodids show a seasonal succession pattern typical of most winter or spring dominant rotifer species. The population density increases rapidly in the late winter or spring, followed by a general decline as water temperatures exceed 10-15°C. During the fall and early winter the organisms exist as resting mictic eggs. This general pattern is also displayed by *Keratella* in Lafayette Reservoir; however, the population maximum occurs earlier (February) with decline to very low densities (<0.1/ℓ) by June.

3.3.2 Biomass

Zooplankton biomass measurements are presented in Figure 3-28. During periods of stratification, the epilimnion biomass (dry-weight) ranged from 23.9 to 488.5 mg/m^3 with a mean of 162.4 mg/m^3. Consistently low biomass ($\bar{x}$ = 15.4 mg/m^3) was observed in the hypolimnion during summer stratification.

Highest epilimnion biomass concentrations (∿1300 mg/m^3) occurred in mid-November just prior to fall turnover (Figure 3-28).

The concurrence of both thermal stratification of the reservoir and vertical stratification of zooplankton biomass is evidenced in Figure 3-28 and 3-29. During the summer zooplankton are confined to

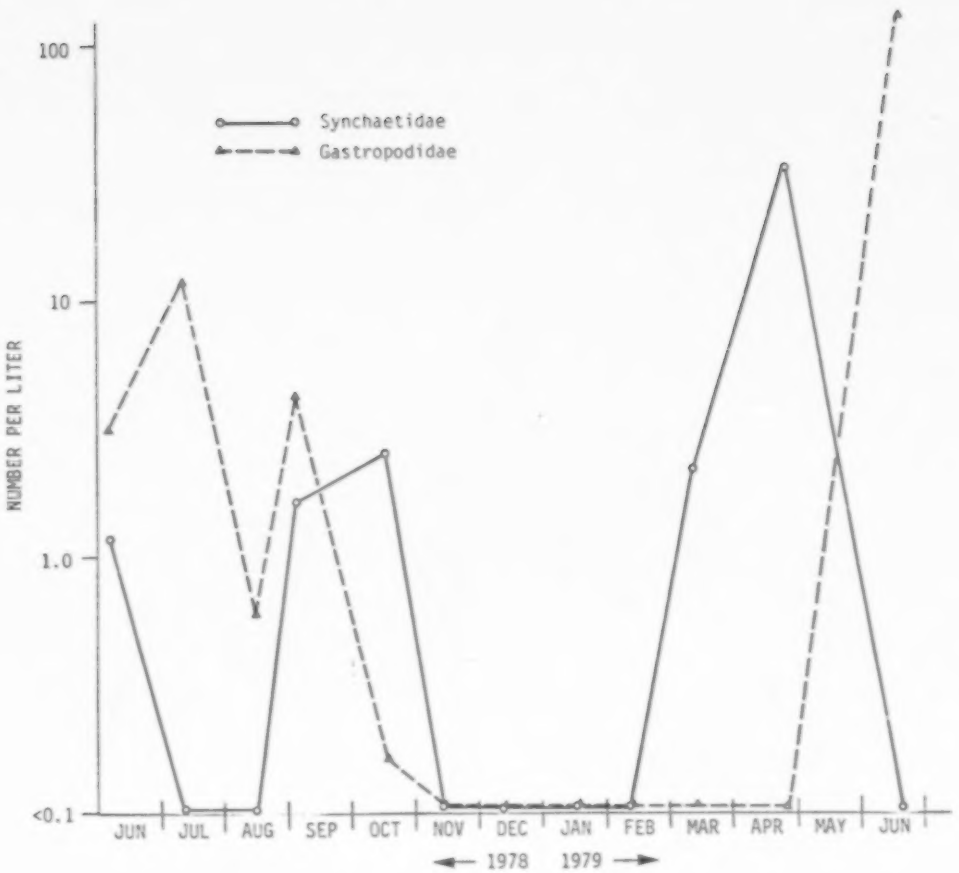

FIGURE 3-27. MEAN ABUNDANCES OF SYNCHAETID AND GASTROPODID ROTIFERS IN 0.5 M AND 5.0 M ZOOPLANKTON SAMPLES

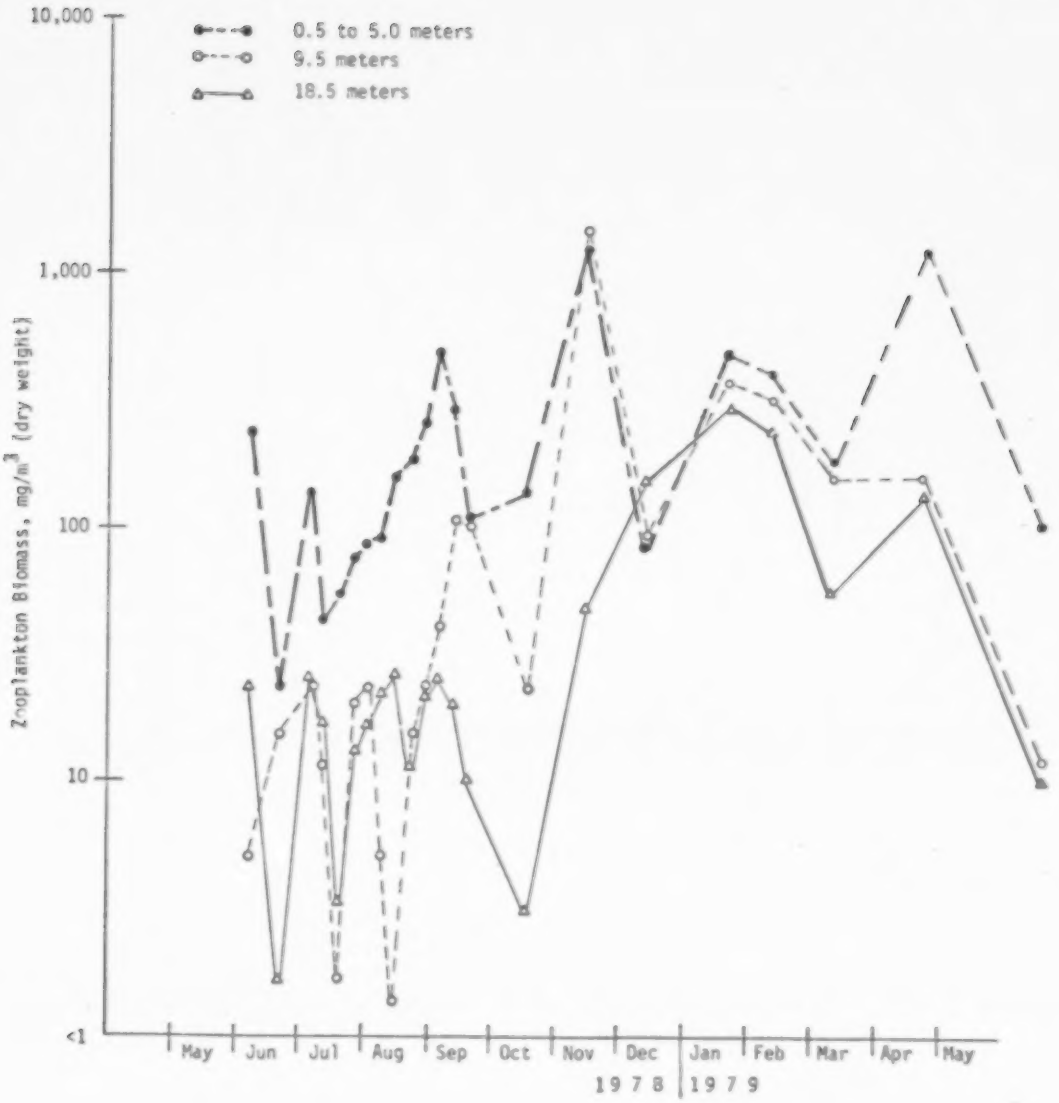

FIGURE 3-28. ZOOPLANKTON BIOMASS AT LAFAYETTE RESERVOIR

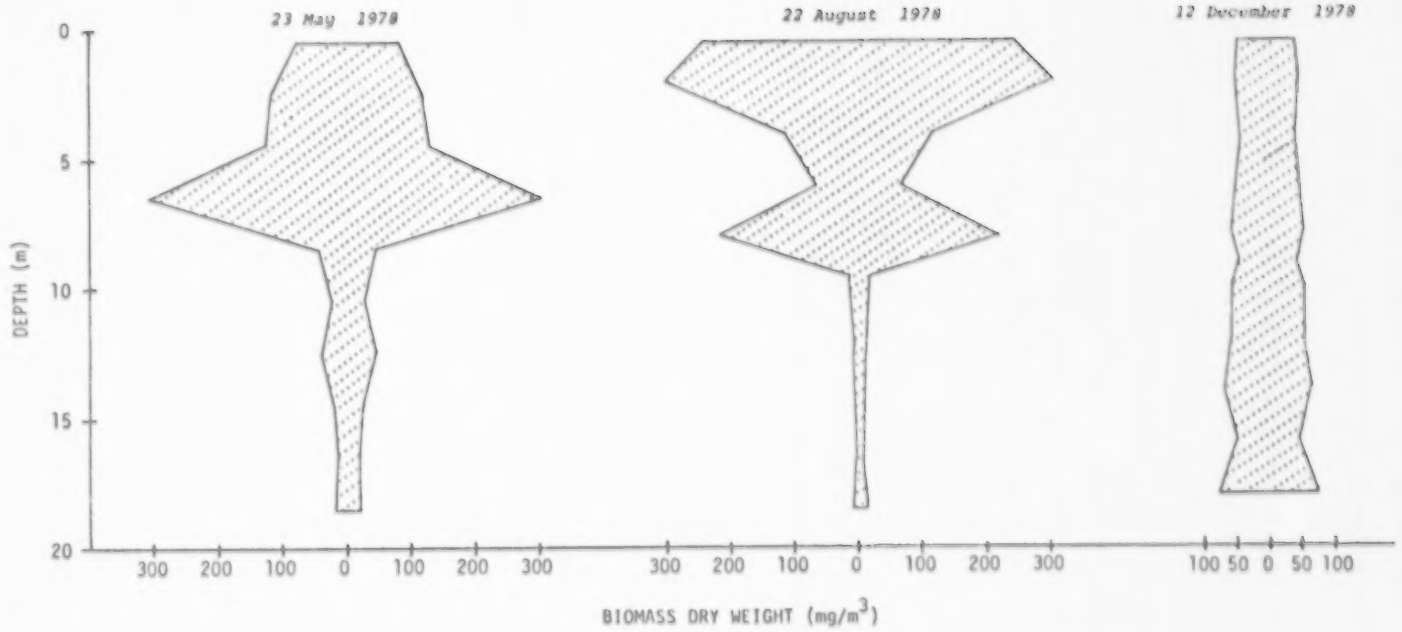

FIGURE 3-29. ZOOPLANKTON DEPTH DISTRIBUTION AT LAFAYETTE RESERVOIR ON THREE SAMPLING DATES

the epilimnion. Following fall turnover, however, the zooplankton concentrations are essentially homogeneous with depth.

It should be emphasized that "zooplankton biomass" as measured by filtered samples is actually a measure of total net (80 μm) seston. Therefore, although zooplankton biomass comprises the majority of the measured material, large phytoplankton (e.g., *Asterionella* and *Fragillaria*) and organic detritus may also contribute to the filtered material. The consistently low densities observed in the hypolimnion are probably the result of filtered detritus (i.e., settling phytoplankton, zooplankton and allochthonous material).

Regression of the total lake biomass of zooplankton on the phytoplankton standing crop as estimated by chlorophyll-a concentration (CA, mg/m^3) showed a positive relationship of reasonably good fit ($r = 0.66$):

$$\text{Zooplankton (kg)} = -170 + 310\ CA$$

The presence of algae, as evidenced by the green color observed in several samples, may have increased the variance in the samples and thus decreased the correlation coefficient.

3.4 BENTHOS

Temperature and dissolved oxygen measurements made near the bottom at the time of benthic sample collections are presented in Table 3-7. From the commencement of the sampling program on 25 April 1978 through October the reservoir was stratified, and the 19 to 21-m profundal stations (B-1 and B-2, Figure 2-2) had very low oxygen concentrations ($\leq$0.1 mg/ℓ). Oxic conditions were first observed at stations B-1 and B-2 on 14 December, and oxygen saturation was estimated at approximately

Table 3-7

TEMPERATURE AND DISSOLVED OXYGEN MEASURED NEAR THE BOTTOM AT BENTHIC SAMPLING STATIONS

Sampling Station (Depth) m	25 April		22 June		23 August		20 October		14 December		14 February		27 April		19 June	
	Temperature °C	D.O. mg/ℓ	Temperature °C	D.O. mg/ℓ	Temperature °C	D.O. mg/ℓ	Temperature °C	D.O. mg/ℓ	Temperature °C	D.O. mg/ℓ	Temperature °C	D.O. mg/ℓ	Temperature °C	D.O. mg/ℓ	Temperature °C	D.O. mg/ℓ
B-1 (19)	11.4	0.1	12.5	0.1	12.0	<0.1	12.5	<0.1	10.6	6.4	8.0	9.1	9.2	0.3	9.3	<0.1
B-2 (21)	11.6	0.1	12.2	0.1	12.2	<0.1	12.4	<0.1	10.6	6.4	8.0	9.1	9.2	0.4	9.8	<0.1
B-3 (10)	12.8	0.1	12.8	<0.1	13.0	<0.1	18.5	2.6	10.6	6.6	8.0	9.4	9.9	0.9	10.9	<0.1
B-4 (3.5)	15.2	7.7	21.3	8.9	22.3	6.9	19.4	7.6	10.8	6.7	10.8	12.2	16.6	10.6	21.2	8.0

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57%. The highest percentage saturation of oxygen (77%) was recorded at the deep profundal stations on 13 February 1979, but by April, 1979 the reservoir had again stratified and low oxygen concentrations ($\leq$0.1 mg/ℓ) were recorded. Temperature at stations B-1 and B-2 ranged from 8.0 to 12.5°C during the sampling program. Station B-3 which was near the upper limit of the hypolimnion was also anoxic during the spring and summer, but oxic conditions were established at the depth of this station (10.0 m) prior to complete mixing of the reservoir. Temperatures at the upper end of the range recorded at station B-3 were greater than those recorded at the deeper profundal stations; temperatures ranged from 8.0 to 18.5°C. The littoral station, B-4, was always under oxic conditions, with dissolved oxygen values ranging from 6.7 to 12.2 mg/ℓ. Temperatures at this station ranged from 10.8 to 22.3°C.

The benthic communities sampled at Lafayette Reservoir were comprised of only three major taxa: two groups of dipteran larvae (*Chaoborus* sp. and Chironomidae) and oligochaetes.

Highest values for total benthic dry-weight biomass (5.2-7.6 g/m^2) were observed in April 1978 at the 19 to 21-m profundal stations, B-2 and B-2 (Table 3-8, Figure 3-30). The total biomass at these areas then displayed a general decline during the period of stratification. By December the total biomass at stations B-1 and B-2 was less than 0.5 g/m^2. The total biomass at station B-2 increased to approximately 2.5 g/m^2 by the following sampling event in February 1979 and remained relatively constant throughout the remainder of the sampling program. The benthic biomass at station B-1, however, remained low (<1.0 g/m^2) during the period December to April 1979 but exhibited a marked increase on the final sampling event. The total biomass at the littoral station B-4 and shallower profundal station B-1 (10 m) was less variable seasonally and ranged from about 0.3 to 2.3 g/m^2.

Table 3-8

BIOMASS (g/m^2 DRY WEIGHT) OF BENTHIC MACROINVERTEBRATES AT LAFAYETTE RESERVOIR DURING THE PERIOD APRIL-DECEMBER, 1978

(All numbers are means of two replicate samples)

Date	Collection Station	*Chaoborus* sp.	Chironomidae	Oligochaeta	Total
25 April 1978	B-1	2.693	0.456	4.430	7.579
	B-2	2.093	0.529	2.611	5.225
	B-3	0.161	1.931	0.101	2.194
	B-4	0.041	0.480	1.604	2.124
20 June 1978	B-1	0.505	0.315	1.755	2.575
	B-2	0.205	0.315	3.640	4.160
	B-3	0.350	0.350	0.075	1.200
	B-4	--	0.075	1.075	1.150
23 August 1978	B-1	0.130	0.220	0.705	1.055
	B-2	0.140	0.000	2.315	2.455
	B-3	0.215	1.826	0.000	2.041
	B-4	0.000	0.005	0.695	0.700
20 October 1978	B-1	0.224	0.000	0.338	0.562
	B-2	0.194	0.011	2.535	2.740
	B-3	0.265	0.000	0.028	0.293
	B-4	0.037	0.017	0.855	0.909
14 December 1978	B-1	0.220	0.000	0.080	0.300
	B-2	0.284	0.000	0.211	0.495
	B-3	0.470	1.901	0.034	2.405
	B-4	<0.005	0.000	1.253	1.257
14 February 1979	B-1	0.320	0.140	0.130	0.590
	B-2	0.330	0.030	1.840	2.200
	B-3	0.180	2.160	0.250	2.590
	B-4	--	0.220	1.500	1.720
25 April 1979	B-1	0.220	0.240	0.100	0.560
	B-2	0.270	0.020	1.370	1.660
	B-3	0.150	1.980	0.310	2.450
	B-4	--	0.004	0.250	0.250
17 June 1979	B-1	0.450	0.070	1.190	1.710
	B-2	0.100	--	2.280	2.380
	B-3	0.400	1.250	0.080	1.720
	B-4	0.190	0.030	0.270	0.500

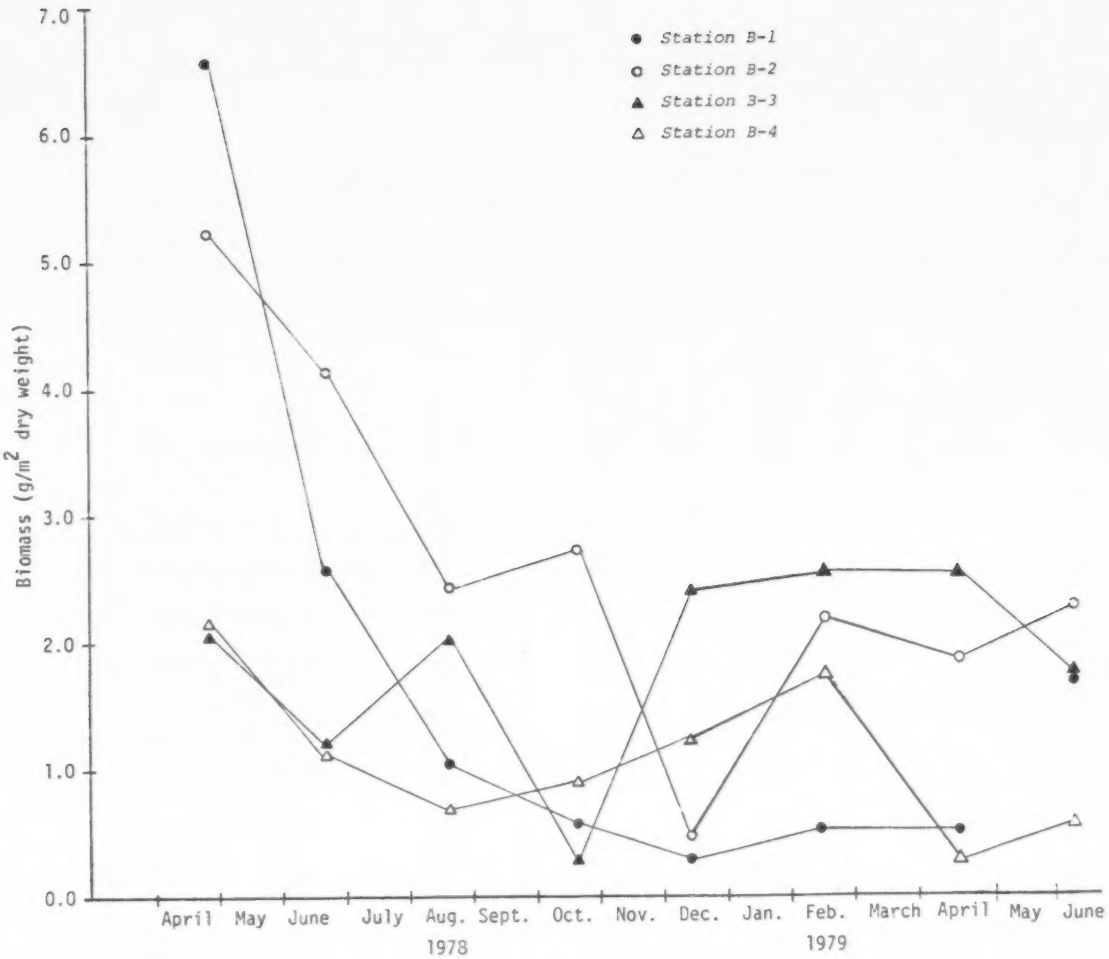

FIGURE 3-30. BIOMASS OF TOTAL BENTHIC MACROINVERTEBRATES AT LAFAYETTE RESERVOIR

The general trend in total macroinvertebrate biomass described above was reflected in the biomass of oligochaetes at the deeper profundal stations as well as the littoral station (Figure 3-31). Oligochaetes, moreover, comprised from 54 to 100% of the total benthic biomass of the littoral station (B-4) throughout the study. And the proportion of the total biomass accounted for by oligochaetes was similarly high at stations B-1 and B-2 on all sampling events in which the total biomass was greater than 1.0 g/m^2. Densities of oligochaetes at the 10-m profundal station (B-3), as indicated by dry weight measurements (0.3 g/m^2), were consistently low. Chironomid larvae comprised 65 to 90% of the total biomass of station B-3 on all but one occasion.

Dipteran larval densities displayed distinct patterns according to water depth. Recorded *Chaoborus* densities at stations B-1 and B-2 were similar (Figure 3-32). Highest densities occurred during April 1978, declined by about an order of magnitude through August and then increased by October and remained relatively constant at numbers greater than 1000/m^2 throughout the study. At station B-3, *Chaoborus* densities were similar to the deeper profundal stations, except that the densities were considerably lower in April 1978 and during the period February to April 1979.

During the period June through August 1978, no *Chaoborus* were collected at the littoral station and only very low densities (<115 organisms/m^2) were observed during other sampling periods (Figure 3-32). This general depth distribution is consistent with the known behavioral characteristics of most *Chaoborus* larvae. They are generally benthic or epibenthic during the day at the deepest parts of the water body and then undergo a pronounced vertical migration to the epilimnion at night. Although no night samples have been collected at Lafayette Reservoir, it is presumed that *Chaoborus* feed in the epilimnion at night since they are mainly zooplanktivorous and little food would be available in the hypolimnion.

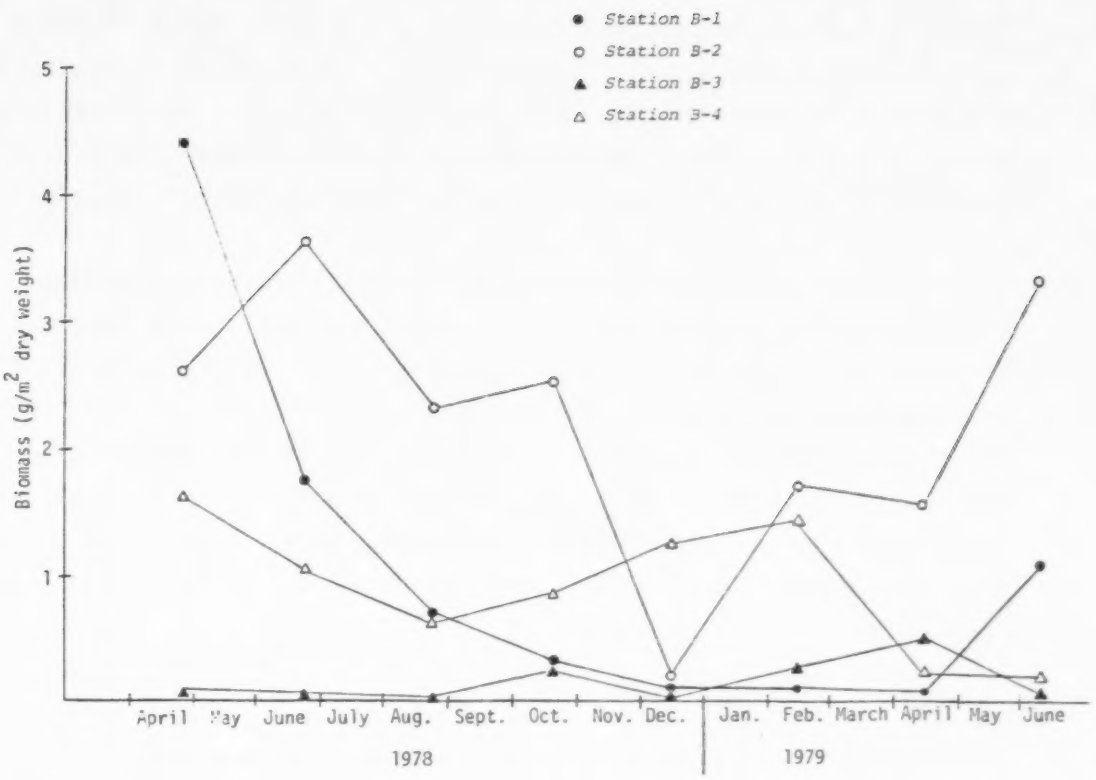

FIGURE 3-31. DRY WEIGHT BIOMASS OF OLIGOCHAETES AT LAFAYETTE RESERVOIR

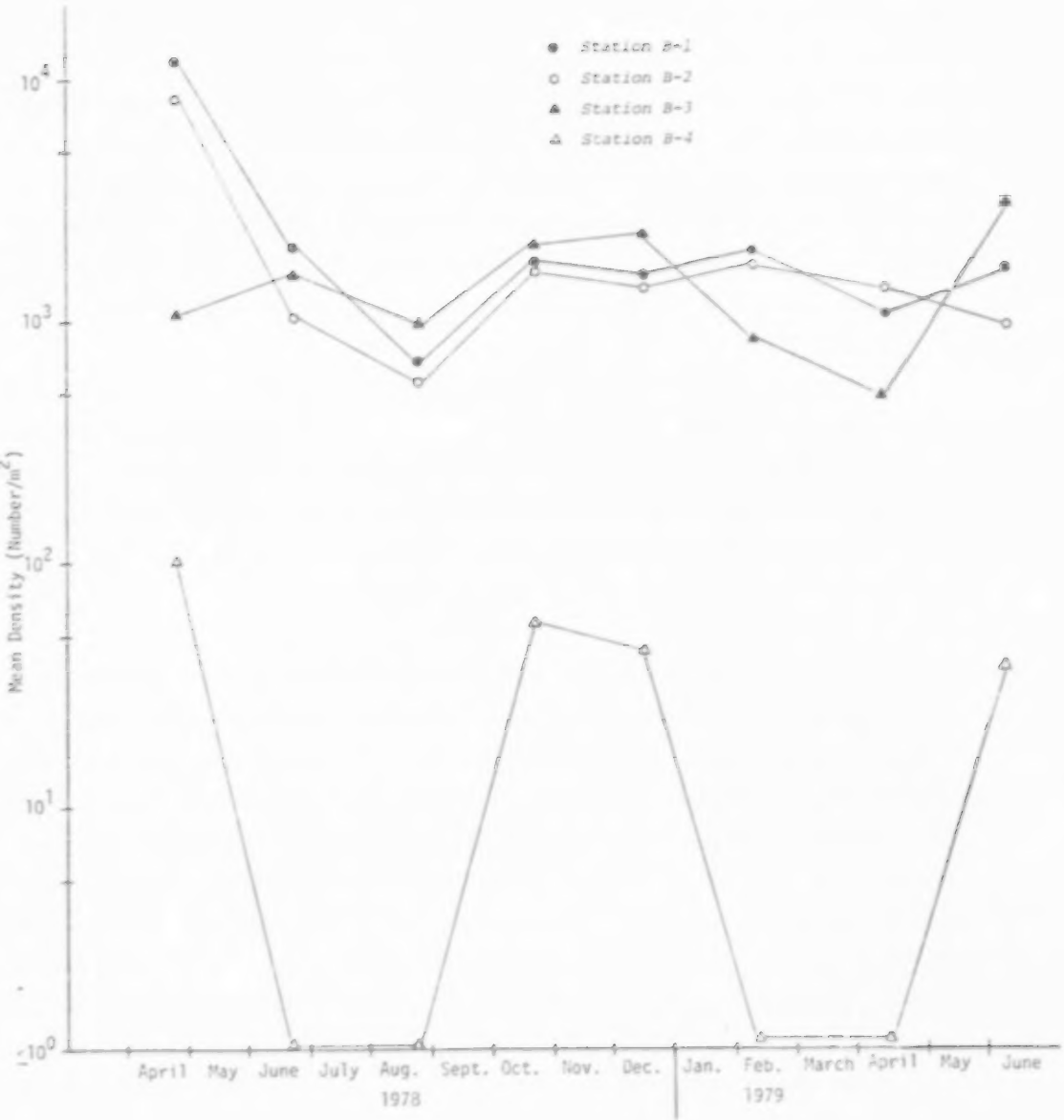

FIGURE 3-32. DENSITIES OF *Chaoborus* SP. LARVAE AT LAFAYETTE RESERVOIR. (INDICATED DENSITIES ARE THE MEANS OF THREE REPLICATE SAMPLES)

The densities of chironomid midge larvae were highly variable, both spatially and temporally (Figure 3-33). In general, however, maximum occurrences of chironomids occurred in the shallower areas at stations B-3 and B-4. Although densities generally declined during stratification, relatively low numbers of chironomids occurred during anoxic conditions at the 18 to 21-m stations during the June-August 1978 and June 1979 sampling periods. The chironomids occurring in Lafayette Reservoir have a type of haemoglobin which enables them to obtain dissolved oxygen at very low concentrations. Chironomids may also survive for substantial periods under anaerobic metabolism.

The profundal benthos of Lafayette Reservoir maintains relatively high average biomass levels (>1 g/m^2) throughout the period of thermal stratification. The June, August and October profundal benthos samples averaged 1.91 g/m^2. During this period the reservoir had been stratified for at least three months and bottom dissolved oxygen concentrations were below detectable limits (<0.1 mg/ℓ).

Following stratification and the establishment of an anoxic hypolimnion, the mean profundal biomass was approximately twice that of littoral areas (0.82 g/m^2). In February, following complete mixing, the average profundal and littoral benthic standing crops were similar at 1.79 g/m^2 and 1.72 g/m^2, respectively. Based on measured biomass values, the profundal benthic communities were dominated by chironomids and oligochaetes with both groups comprising about 86% of the average total biomass. This is an important distinction since the chironomids and oligochaetes would both be considered as "resident" members of the profundal benthos. These biotic groups may be contrasted to *Chaoborus* which has considerable vertical mobility and could conceivably migrate to oxic conditions in the epilimnion on a daily basis.

The profundal benthic area of Lafayette Reservoir represents approximately 53% of the total benthic area (assuming maximum pool and a 10-m depth of thermocline base). Therefore, the benthic production

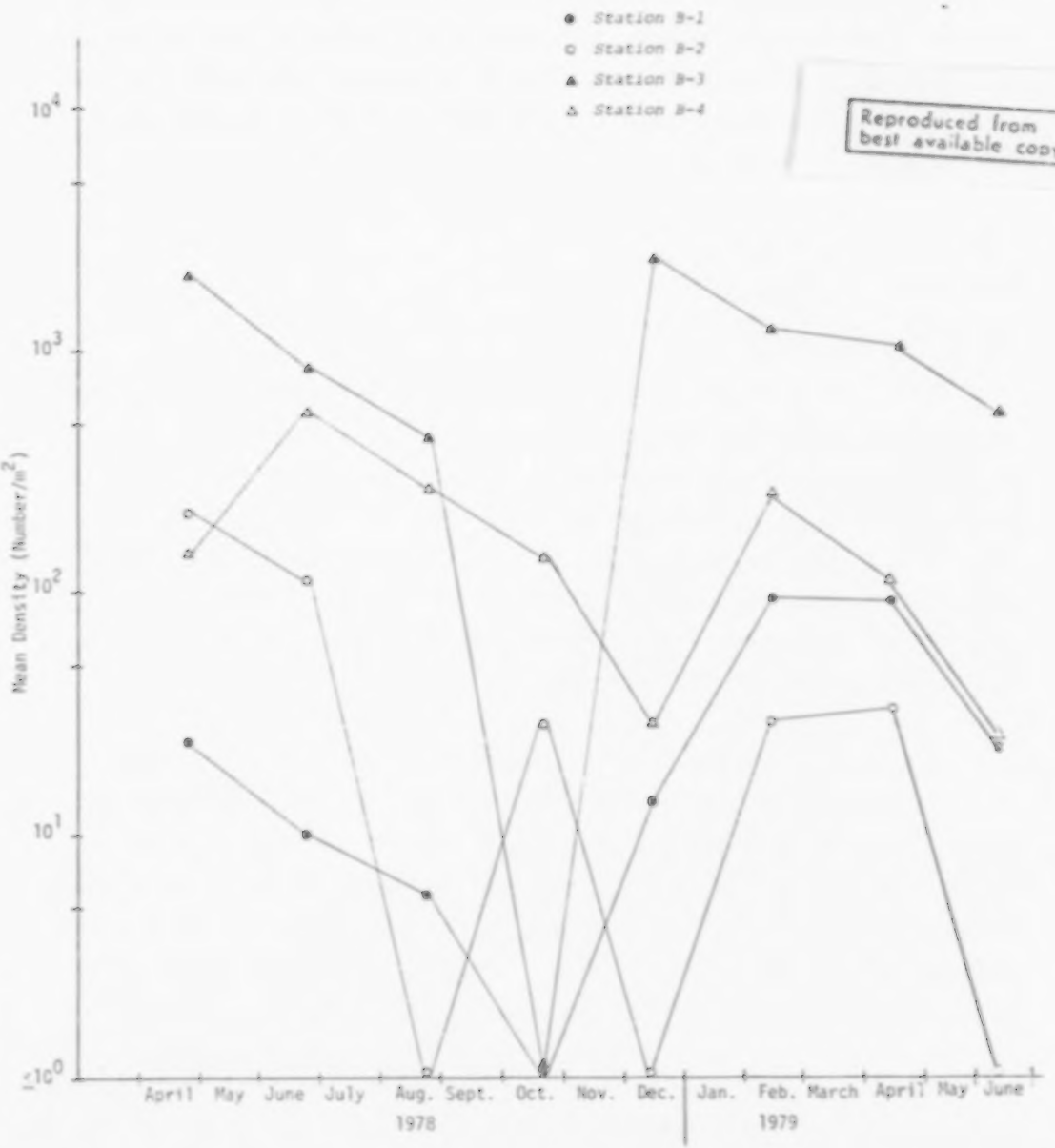

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FIGURE 3-33. DENSITIES OF CHIRONOMID LARVAE AT LAFAYETTE RESERVOIR. (NUMBERS ARE THE MEANS OF THREE REPLICATE SAMPLES.)

of the profundal zone is quite important to the overall production of benthic invertebrates in Lafayette Reservoir. Moreover, due to the extended period of stratification (up to 9 months), the benthic production of the reservoir would be extremely limited if it were dependent upon oxic conditions.

3.5 FISH

3.5.1 Angler Survey

Table 3-9 is a summary of bank anglers interviewed and the catch composition during the period of 23 June 1978 to 6 March 1979. A total of 399 bank anglers was interviewed. During each angler interview period (1400-1600 on indicated day), the total number of bank and boat anglers was also estimated. Due to the limited number of boat anglers, only bank anglers have been included in the survey. However, during the current reporting period, 76% of the bank anglers present during the survey period were interviewed.

In general boat anglers represented less than 15% of the total angling pressure on Lafayette Reservoir on a given day. Although the success rate of boat anglers is probably higher than that of bank anglers (especially for trout), the relative usage of boats for fishing Lafayette Reservoir is quite low due to limited access. Fishing boats must be rented from a concession, and no gasoline-powered motors are allowed.

The angler catch at Lafayette Reservoir is comprised almost entirely of rainbow trout (54%) and bluegill (44%). Black crappie and Sacramento blackfish were the only other species observed and contributed only about 2% to the total catch.

Table 3-10 describes the trout stocking program conducted by California Department of Fish and Game in Lafayette Reservoir. Legal sized

Table 3-9

RESULTS OF ANGLER INTERVIEW PROGRAM AT LAFAYETTE RESERVOIR

Date	Number Interviewed	Total Angler-Hours	Total Catch			
			Trout	Bluegill	Crappie	Sacramento blackfish
23 June	13	61.5	24	91	1	0
3 July	16	54.5	6	33	6	1
12 July	38	116.0	32	20	2	1
19 July	12	59.5	18	18	0	1
21 July	21	83.0	8	13	0	0
27 July	27	92.0	39	14	0	0
3 August	30	52.0	8	0	0	0
10 August	14	27.5	1	3	0	0
18 August	21	68.0	2	7	0	0
25 August	15	51.0	6	0	0	0
31 August	26	88.8	1	0	0	0
8 September	14	45.0	8	0	0	0
15 September	11	40.0	13	0	0	0
1 October	16	26.0	1	40	0	0
3 November	12	25.0	5	4	0	0
30 November	6	20.5	3	0	1	0
19 January	23	41.5	18	0	0	0
25 January	31	99.8	64	0	0	0
7 February	25	60.8	40	0	0	0
6 March	28	100.8	37	0	0	0
7 June	39	101.5	28	18	15	0
6 March	28	100.8	37	0	0	0

Table 3-10

TROUT STOCKING SCHEDULE AT LAFAYETTE RESERVOIR

Date	Number	Average Weight (No./lb.)
1978		
17 January	2500	4.8
30 January	2675	4.3
16 February	2055	3.0
27 February	2800	4.0
14 March	2500	4.3
28 March	2500	4.0
10 April	1360	2.7
26 April	2000	5.3
12 May	1500	2.5
6 June	3500	4.1
30 June	3000	4.0
12 July	2538	3.5
18 July	4000	3.2
6 September	3000	4.0
20 September	3000	4.9
5 October	3000	3.4
1 November	1200	4.7
16 November	1000	5.2
29 November	1332	4.5
7 December	1250	5.2
1979		
5 January	2500	4.2
19 January	5000	5.0
25 January	2000	5.0
6 February	2630	3.8
13 February	2180	4.9
27 February	3000	4.5
8 March	3500	3.5
22 March	3500	5.0

trout were stocked at somewhat irregular intervals except during the period of 19 July to 5 September, when stocking was discontinued due to high surface water temperatures. The summer lapse in stocking normally occurs as surface water temperatures exceed approximately 24°C. The average weight of trout stocked during the study period ranged from 88 to 181 g.

The DFG currently stocks only trout in Lafayette Reservoir. In the past warm water species such as largemouth bass, channel catfish and bluegill have also been intentionally introduced. There have also been incidental introductions of many species native to the Mokelumne River (e.g., white catfish and Sacramento blackfish) through the former water supply aqueduct. Additionally, fishes salvaged from San Pablo Reservoir (which was drained for dam construction) were stocked in Lafayette Reservoir during the late fall, 1978. The transferred fishes were comprised primarily of the following species: channel catfish, black crappie and largemouth bass.

The trout catch rate displayed a wide variation from 0.01 to 0.66 per angler-hour (Figure 3-34). The overall average trout catch rate for the study period was 0.24 per angler-hour. The lowest catch rates occurred during August. During the fall and winter the catch rate displayed an increasing trend, reaching the maximum rates observed in February (0.66/angler-hour).

The maximum trout catch rates occurred when the lake was isothermal during January and February; however, moderate catch rates exceeding 0.3 trout per angler-hour were also observed in the early summer. Moreover, the catch rate reached 0.42 fish per angler-hour on 27 July when epilimnion temperatures were about 24.5°C and the lake had been stratified, with an anoxic hypolimnion, for at least 3 months.

During June and July the majority of anglers interviewed also indicated that their perception of the fishing quality at Lafayette

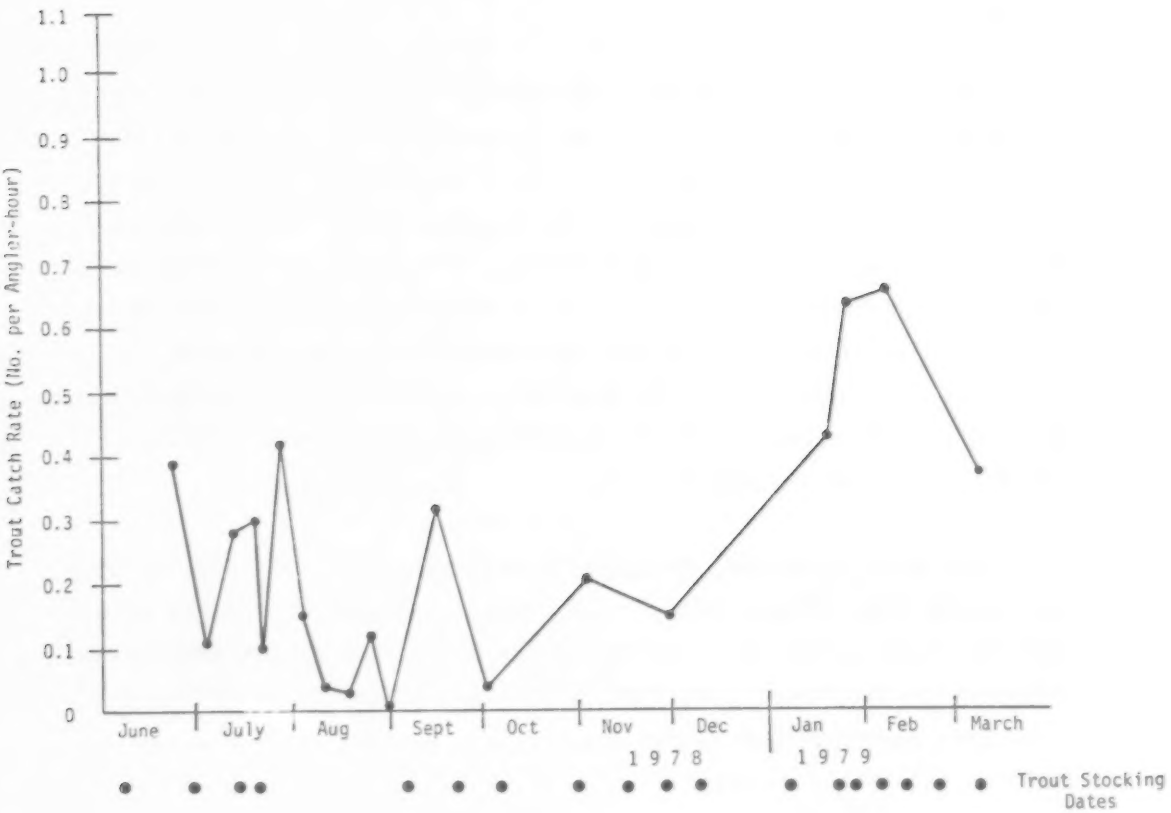

FIGURE 3-34. TROUT CATCH RATE AT LAFAYETTE RESERVOIR

Reservoir was at least "good". The proportion of such positive responses to questions concerning fishing quality dropped considerably following cessation of stocking in August.

During the summer the trout habitat at Lafayette Reservoir is suboptimal due to confinement of stocked trout to the warm epilimnion. However, the angling usage and catch rate appear to be sustained at moderate levels as long as trout are stocked. The rapid decline of angling success following cessation of stocking indicates, however, that the survival time of trout stocked during the summer may be quite limited. The low survival rate of stocked trout is also indicated by an examination of the size of angler caught trout. The average weight of trout measured during the angler interviews was 114 g. Comparisons with the average weight of stocked trout during the same period (108 g) indicates that there is little growth of stocked trout prior to being caught.

The low survival and/or growth is probably due to a combination of high epilimnion temperatures and predation by largemouth bass. The angler success rate during the period of thermal stratification is probably limited due to a lack of knowledge concerning trout distribution. Interviews of local anglers indicated that some did not realize that anoxic conditions existed in the hypolimnion. These individuals continued to fish in cooler deep waters without success during the summer and fall.

The catch of warmwater species (primarily bluegill) occurred mainly during June and July. A low proportion of the total angling pressure at Lafayette Reservoir is directed toward warmwater species. However, bluegill are relatively easy to catch, and the total numbers listed in Table 3-9 represent the combined catch of only a few individuals. The catch rate for bluegill anglers is therefore quite high. Some of the warmwater species are also caught incidentally by trout anglers.

The potential angling pressure at Lafayette Reservoir is limited by the aforementioned boat access and also by the shoreline access. The shoreline of Lafayette Reservoir is lined with dense stands of large emergent plants such as *Typha* and *Scirpus*. Therefore, shore angling is essentially restricted to floating docks or small gaps in the vegetation. The fishing docks installed by EBMUD are identified on the vegetation map, Figure 3-36. Although the maximum potential instantaneous shoreline angling pressure cannot be accurately estimated, it is felt that, with current access, shoreline angling by more than 75 persons would result in crowding of available space.

3.5.2 Species Composition and Depth Distribution

Experimental gill nets fished during the spring, summer and winter collected a total of 351 fish representing six species. The spring-summer catch was dominated by Sacramento blackfish *(Orthodon microlepidotus)* and black crappie *(Pomoxis nigromaculatus)* (Table 3-11). The winter collections were comprised almost entirely of black crappie (85.8%), with no blackfish being collected. Trout were collected infrequently during all three sampling periods at rates of 1.6 to 8.6% of the total catch. Bluegill *(Lepomis macrochirus)*, largemouth bass *(Micropterus salmoides)* and hitch *(Lavinia exilicauda)* were also collected at relatively low frequencies during the sampling period. Additional fish species collected by vertical gill nets, but not in experimental gill nets, were the brown bullhead *(Ictalurus nebulosus)* and white catfish *(Ictalurus catus)*. Three other species are also reported to occur in Lafayette Reservoir (California Department of Fish and Game, personal communication) but were not observed in the present study: channel catfish *(Ictalurus punctatus)*, goldfish *(Carassius auratus)* and green sunfish *(Lepomis cyanellus)*.

The species composition difference between winter and spring-summer gill net collections is most likely due to behavioral differences among fish species. Black crappie remain active throughout the year

Table 3-11

SPECIES COMPOSITION OF EXPERIMENTAL
GILL NET COLLECTIONS AT LAFAYETTE RESERVOIR

Species	Percent of Catch	
	Spring-Summer	Winter
Sacramento Blackfish	41.1	0.0
Black Crappie	48.4	85.7
Bluegill	6.3	5.7
Largemouth Bass	2.2	0.0
Rainbow Trout	1.6	8.6
Hitch	0.3	0.0

and were collected during all three seasons. However, the absence of Sacramento blackfish in winter collections indicates that that species is most likely dormant during cooler ambient temperatures. The winter dormancy of blackfish is especially indicated by their absence in littoral, open-water surface and deep-water net sets.

A total of 59 fish was collected in the summer vertical gill net sets; however, no rainbow trout were observed. This low catch rate would be expected due to the corresponding low occurrence of rainbow trout (1.6%) in the experimental gill net samples. At stations S-1 (depth=18.5 m) the catch was comprised entirely of Sacramento blackfish, which, with the exception of one individual, was distributed above the 7.5 m depth interval (Table 3-12). At the shallower station, S-3 (9.5 m), the blackfish also occurred at depths less than 7.5 m (Table 3-13). A similar distribution was observed at station S-3 for the three other species collected (brown bullhead, black crappie and bluegill).

The vertical gill net data indicate that blackfish and other fish species are essentially confined to the epilimnion during the period of summer stratification. Temperature and dissolved oxygen profiles presented in Figure 3-35 indicate that the epilimnion extended to a depth of about 7 m during the study period. Highest numbers of fish were collected near the bottom of the epilimnion, since 54% of the total fish collected occurred in the range of 5.5 to 7.5 m. The lower limit of fish distribution corresponded to dissolved oxygen concentrations of about 1-2 mg/ℓ.

At the time of the winter fish distribution survey the reservoir was isothermal at about 9°C and dissolved oxygen was about 8 mg/ℓ, displaying little variation with depth. As was the case in winter experimental gill net samples, the catch was comprised mainly of black crappie (92%). The black crappie occurred almost entirely at depths from 9-18 m;

Table 3-12

DEPTH DISTRIBUTION OF SACRAMENTO BLACKFISH
AT LAFAYETTE RESERVOIR STATION S-1 ON 20-24 AUGUST, 1978

Depth (m)	Total Catch	Percent
0.5 - 1.5	4	12.5
1.5 - 2.5	3	9.4
2.5 - 3.5	5	15.6
3.5 - 4.5	1	3.1
4.5 - 5.5	3	9.4
5.5 - 6.5	5	15.6
6.5 - 7.5	10	31.3
7.5 - 8.5	1	3.1
8.5 - 9.5	0	0.0
9.5 -18.5	0	0.0
TOTAL:	32	100.0

Table 3-13

DEPTH DISTRIBUTION OF SACRAMENTO BLACKFISH AND OTHER FISH SPECIES AT LAFAYETTE RESERVOIR STATION S-3 ON 16-19 AUGUST, 1978

Depth (m)	Sacramento Blackfish		Other Species*	
	Total Catch	Percent	Total Catch	Percent
0.5 - 1.5	1	6.2	0	0.0
1.5 - 2.5	4	25.0	1	9.1
2.5 - 3.5	1	6.2	1	9.1
3.5 - 4.5	0	0.0	0	0.0
4.5 - 5.5	0	0.0	2	18.2
5.5 - 6.5	8	50.0	6	54.5
6.5 - 7.5	2	12.5	1	9.1
7.5 - 8.5	0	0.0	0	0.0
8.5 - 9.5	0	0.0	0	0.0
TOTAL:	16	99.9	11	100.0

*Brown Bullhead, Black Crappie, and Bluegill

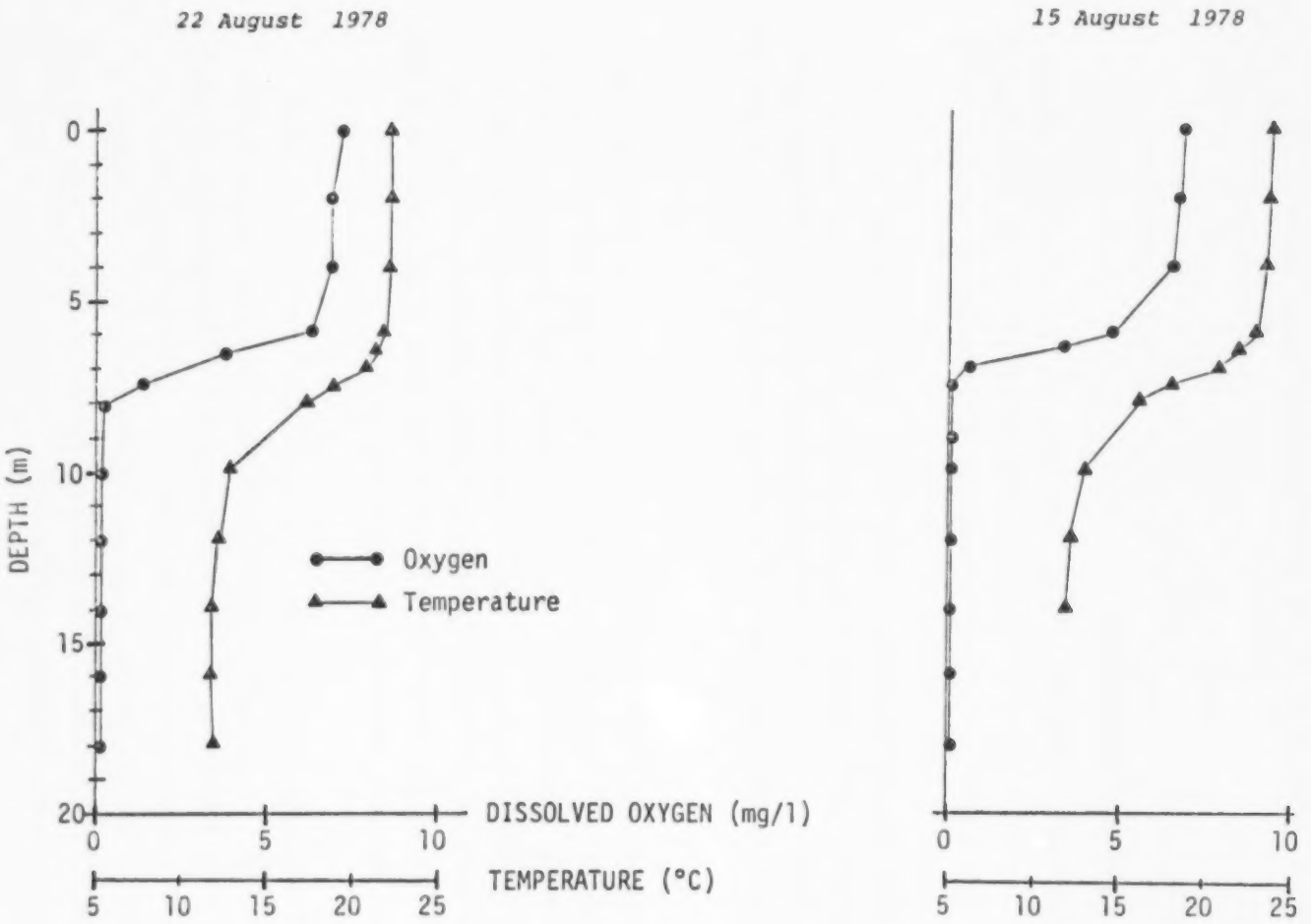

FIGURE 3-35. DISSOLVED OXYGEN AND TEMPERATURE PROFILES DURING THE VERTICAL GILL NET SURVEY AT LAFAYETTE RESERVOIR

only one individual was collected at shallower depth intervals (Table 3-14). When all species were considered, the total fish distribution was similar, with 95.5% of the collected fish occurring below 9 m.

3.6 MACROPHYTES

3.6.1 Submergent Macrophytes

The common freshwater alga, *Chara* spp. and the waterwort *Elatine californica* were identified from samples collected within the littoral zone. Nine samples, each containing the plant material removed from a 0.25 m^2 quadrat, were collected from the areas shown in Figure 2-2. The maximum dry-weight biomass measured in these areas was 63.6 g/m^2. The recorded values ranged from 1.4 to 63.6 g/m^2, and the mean dry-weight biomass was 4.5 g/m^2. Diver observations in the littoral zone indicated that submerged macrophyte growth occurred down to a depth of 4.7 m.

These observations and measurements indicate that the total dry-weight biomass of submerged macrophytes in Lafayette Reservoir is approximately 4.5×10^2 kg. This value represents the product of the calculated mean dry-weight biomass from nine samples and the area of the reservoir within the submerged macrophyte growth zone, i.e., an area defined by the observed depth distributional limits and the areal extent of emergent macrophytes (described below).

The observed distributional limit of submergents in Lafayette Reservoir (4.7 m) was approximately 1.6 times the mean Secchi depth (2.9 m) recorded during the period May-August. This value is somewhat lower than reported ratios of distribution limits to Secchi depth, which range from 2-5 (Porcella et al., 1979), and suggests factors other than light attenuation as measured by the Secchi disc may affect submergent growth in Lafayette Reservoir.

Table 3-14

Depth Distribution of Fishes Collected at Lafayette Reservoir
During the Winter Vertical Gill Net Survey, 3-9 January, 1979

Depth (m)	Black Crappie		Other Spp.	Total	
	Number	Percent		Number	Percent
0-1	0	0.0	1 Sacramento blackfish	1	1.5
1-2	0	0.0	--	0	0.0
2-3	0	0.0	--	0	0.0
3-4	0	0.0	--	0	0.0
4-5	0	0.0	1 Rainbow trout	1	1.5
5-6	0	0.0	--	0	0.0
6-7	1	1.7	--	1	1.5
7-8	0	0.0	--	0	0.0
8-9	0	0.0	--	0	0.0
9-10	2	3.3	--	2	3.1
10-11	1	1.7	--	1	1.5
11-12	7	11.7	2 Bluegill	9	13.8
12-13	7	11.7	1 White catfish	8	12.3
13-14	10	16.7	--	10	15.4
14-15	7	11.7	--	7	10.8
15-16	8	13.3	--	8	12.3
16-17	7	11.7	--	7	10.8
17-18	10	16.7	--	10	15.4
TOTAL	60	100.0		65	100.0

3.6.2 Emergent Macrophytes

The map shown in Figure 3-36 was produced from aerial and field survey data and delineates the emergent macrophyte stands along the reservoir shoreline. During the field surveys three species of emergents were identified; these were: the bulrushes *Scirpus californicus* and *S. acutus* and the cattail *Typha domingensis*. The emergent stands identified on the reservoir were small and except in a few instances occurred in very narrow bands. Generally, individual plants extended no more than 2.25 m below the waterline.

The areal extent of individual stands on the reservoir were measured from the prepared map using a planimeter. The areal coverage of the dominant species, *Scirpus californicus*, was determined to be 0.88 hectare, and the measured areal coverage of *Typha domingensis* and *Scirpus acutus* was found to be 0.53 hectare and 0.28 hectare, respectively. The total areal extent of emergent macrophyte growth, 1.69 hectares, was found to represent approximately 3.0% of the total surface area of the reservoir.

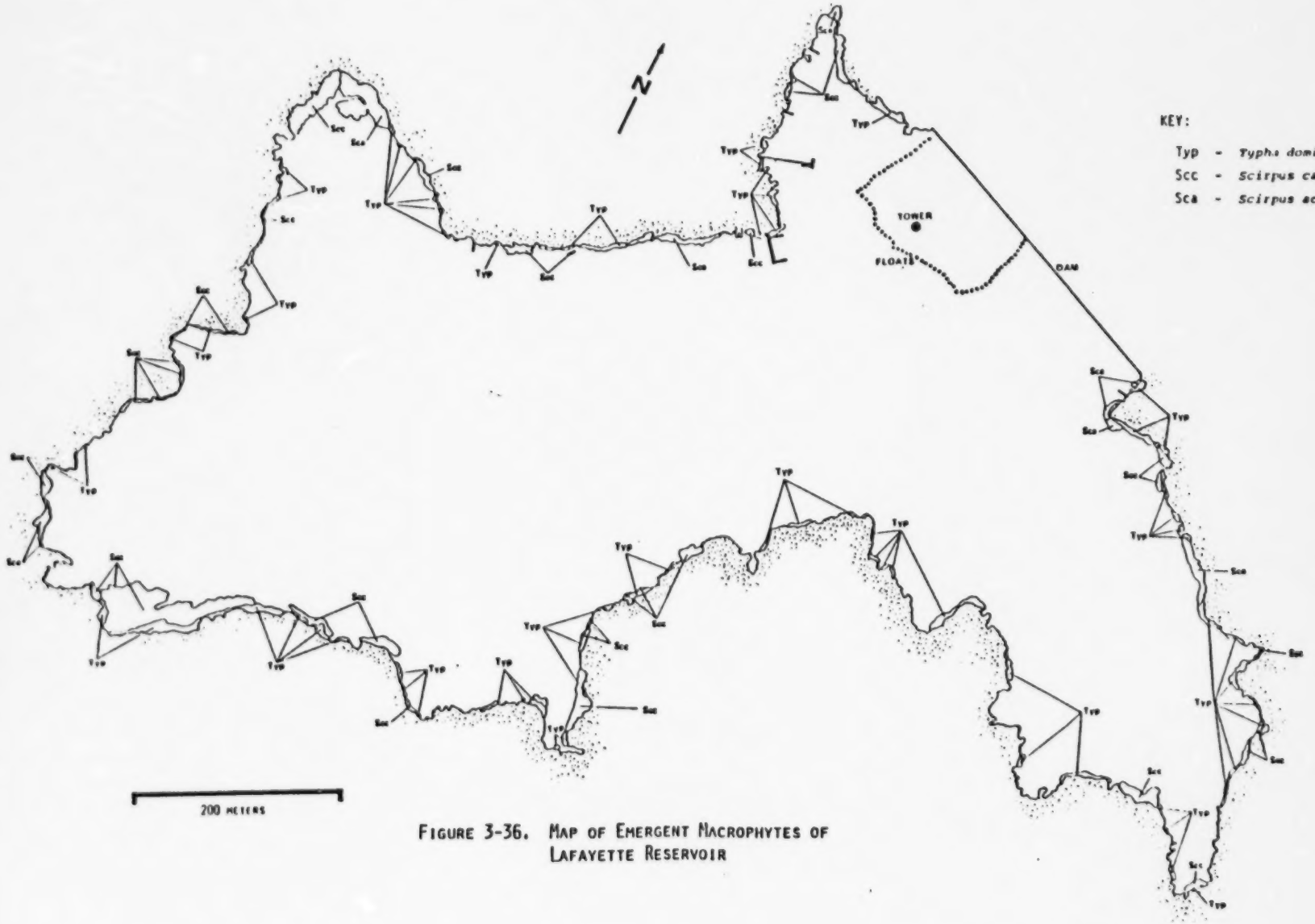

FIGURE 3-36. MAP OF EMERGENT MACROPHYTES OF LAFAYETTE RESERVOIR

4.0 SUMMARY AND DISCUSSION

Although external nutrient inputs to Lafayette Reservoir from the relatively small, undisturbed watershed are low, nutrients which enter the system become temporarily sequestered in the sediments. Thus, the reservoir is a nutrient sink in which nutrient dynamics are predictable, self-sustaining and controlled primarily by temperature and light seasonal cycles. The reservoir is highly productive, which results in oxygen depletion in the hypolimnion during thermal stratification and the concomitant regeneration of nutrients from the sediments on an annual cycle.

A consequence of the release of nutrients from the sediments is a marked increase in the phytoplankton standing crop. As these studies indicate, initially the response to increased nutrient availability in the photic zone following mixing is an increase in the abundances of diatoms. The system, however, becomes nitrogen limited (N:P ratios were less than eight throughout the year except during periods when nitrogen fixing blue-green algae were abundant), and fall and early winter blooms of diatoms are displaced by rapidly increasing populations of blue-green algae, e.g., *Anabaena* and *Aphanizomenon*.

In response to peaks in blue-green algae observed in May 1978 and in June 1979, the reservoir was treated with the algicide, copper sulfate ($CuSO_4$). The reservoir was treated with copper sulfate one or more times annually in order to control the growth of blue-greens and mitigate taste and odor problems.

The apparent high productivity of phytoplankton and the continued management of these organisms in Lafayette Reservoir affects higher trophic levels in the ecosystem. A direct correlation exists between phytoplankton standing crop (as estimated by chlorophyll-a concentrations) and total lake zooplankton biomass. Given the fact that

allochthonous organic inputs to the system are low and potential nutrient releases from littoral vegetation are minimal, we assume that phytoplankton production in the reservoir is primarily responsible for the observed zooplankton biomass, and that established management techniques offer at least a partial explanation for the reasonably good fit of these data. Treatment of the reservoir with copper sulfate prevents large, persistent blooms of blue-green such as *Apanizomenon* and *Anabaena* which, if present, would reduce the ingestion and assimilation efficiency rates and therefore production rates of herbivorous zooplankton.

The production of planktonic algae in Lafayette Reservoir stimulates secondary production and represents the primary energy source of the system. The efficient transfer of this energy to higher trophic levels is indicated by the observation of a large benthic biomass as well as large numbers of predatory cyclopoid copepods, phytoplanktivorous fish (Sacramento blackfish), zooplanktivorous fish species (small centrarchids).

As previously described, the high production in the reservoir results in the depletion of oxygen in the hypolimnion during thermal stratification. Such anoxic conditions in the hypolimnion have been shown to decrease the density and abundance of macroinvertebrates in other eutrophic lakes (Wilhm and McClintock, 1978). However, the existence of anoxic conditions does not appear to adversely affect the total benthic biomass in Lafayette Reservoir.
The dry-weight biomass of benthic macroinvertebrates exceeded 1 g/m^2 throughout the year, and these totals were highest during periods of stratification. Moreover, the mean annual benthic biomass in the reservoir (1.87 g/m or 18.7 kg/ha) compares well with similar values reported for eutrophic lakes (Wetzel, 1975).

Although benthic density was high the diversity of benthic macroinvertebrates was low at the littoral as well as profundal stations throughout the year, and, as previously noted, only three major taxa

were identified from all benthic samples. The absence of ephemeropteran and odonatan larvae in littoral zone samples was especially surprising, but this station may not be representative of other areas in the littoral zone. However, based on these studies, there is no basis for predicting an increase in diversity within the reservoir following hypolimnetic aeration.

The fishery at Lafayette Reservoir is primarily a trout fishery which is supported by frequent stockings. Comparisons of the average weight of trout measured during angler interviews with the average weight of stocked trout as well as measurements of trout caught in experimental gill nets indicates that growth of planted fish does not occur and that these fish do not survive through the summer. The trout fishery currently exists on a "put-and-take" basis, and the most visible effect of restoration measures which establish oxic conditions in the hypolimnion during stratification would be the creation of suitable habitat for the year-long survival of trout.

These studies on Lafayette Reservoir have shown that the inputs of nutrients from the sediments are significant. This characteristic as well as the relatively small size of the reservoir indicate that either chemical precipitants or artificial aeration/circulation techniques could be used to successfully and economically manage nutrient release in Lafayette Reservoir. Although these restoration techniques differ in mechanism, both interfere with sediment nutrient release processes and have been shown to be effective in nutrient removal.

Alum treatment produces an aluminum hydroxide floc that removes by sedimentation to the reservoir bottom particulate phosphorus and aluminum phosphate that precipitates in the water column. The floc covers the sediment and acts as a seal for inhibiting release of phosphorus from the sediments. This dual process can result in up to two years of control of phosphorus from internal lake sources according to published results of studies of Twin Lakes, Ohio (Cooke and Kennedy, 1978), Liberty Lake, Washington (Funk and Baily, 1979), and Medical

Lake, Washington (Gasperino et al., 1978). These studies showed that lake quality improved dramatically and remained at that high level for a significant period of time after alum treatment.

Hypolimnetic aeration and aeration/destratification techniques have also been shown to benefit lake quality (Lorenzen and Fast, 1977). Restoring oxic conditions to hypolimnetic waters can minimize return of sediment released nutrients but generally the most beneficial effect is caused by creating aerobic conditions throughout the water column. Aerobic conditions can result from simple mixing caused by diffused air-lift destratification of lakes. The benficial effects of destratificiation by aeration on a trout fishery has been observed in a highly eutrophic reservoir in Utah, although little measureable change in water quality variables was observed (Drury et al., 1975).

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APPENDIX A

WATER QUALITY DATA FOR LAFAYETTE RESERVOIR

DATE	TIME	DEPTH METERS	DO mg/l	TEMP °C	TOTAL P. mg P/l	TOT. SOL. P. mg P/l	ORTHO P. mg P/l	NO_2-N mg N/l	NO_3-N mg N/l	NH_3-N mg N/l	ORG N mg N/l	KJN mg N/l	pH	ALK mg $CaCO_3$/l
5/10/78	1100	0	8.3	19.5	.020	.008	< .001	< .001	.015	< .01	.64	.64	8.3	138
	1110	1.5	8.2	19.5	.020	.010	< .001	< .001	.015	< .01	.58	.58	8.3	146
	1115	3	8.2	19.0										
	1120	5	8.4	19.0	.017	.009	< .001	< .001	.025	< .01	.70	.70	8.2	144
	1125	7	4.3	15.0										
	1130	8.5	1.0	13.5										
	1135	10	0.6	12.0	.091	.090	.081	.003	.168	.05	.80	.85	7.7	146
	1140	12	0.5	12.0										
	1145	13.5	0.5	11.5										
	1150	15	0.5	11.5	.142	.129	.130	.002	.205	.20	.52	.72	7.7	146
	1155	17	0.4	11.0										
	1200	18.5	0.4	11.0										
	1205	19.5	0.4	11.0	.151	.137	.134	.002	.215	.31	.55	.86	7.7	140
6/6/78	1140	0	8.0	22.3	.021	.009	.001	< .001	.061	.03	.82	.85	8.3	.40
	1145	2	7.5	22.2	.020	.020	.003							
	1150	4	7.3	21.5	.022	.020	.006	< .001	.039	.02	.50	.52	8.0	136
	1155	6	5.6	19.5	.029	.009	.006	< .001	.056	.02	.56	.58	7.9	140
	1200	8	0.1	13.7	.072	.063	.044							
	1205	10	< 0.1	12.0	.130	.128	.122	< .001	.063	.06	.46	.52	7.8	140
	1210	12	< 0.1	11.5	.156	.143	.128							
	1215	14	< 0.1	11.5	.182	.175	.151	< .001	.066	.14	.54	.68	7.8	140
	1220	16	< 0.1	11.5	.200	.164	.151							
	1225	18	< 0.1	11.5	.212	.191	.174	< .001	.106	.20	.45	.65	7.8	140

APPENDIX A (continued)

DATE	TIME	DEPTH METERS	DO mg/l	TEMP °C	TOTAL P. mg P/l	TOT. SOL. P. mg P/l	ORTHO P. mg P/l	NO_2-N mg N/l	NO_3-N mg N/l	NH_3-N mg N/l	ORG N mg N/l	KJN mg N/l	pH	ALK mg $CaCO_3$/l
6/13/78	1400	Surface	8.0	22.3										
	1410	1	7.5	22.3										
	1420	2	7.3	22.2										
	1430	4	7.2	21.5										
	1440	6	5.8	19.5										
	1450	6.5	4.4	17.0										
	1500	7	0.5	16.0										
	1510	8	0.1	13.7										
	1520	10	< 0.1	12.0										
	1530	12	< 0.1	11.5										
	1540	14	< 0.1	11.5										
6/20/78	1001	Surface	7.1	21.5	.016	.008	.003	< .001	< .001	.02	0.61		8.4	144
	1014	2	7.1	21.5	.016	.013	.005							
	1020	4	7.0	21.0	.024	.013	.003	.001	.001	.02	0.65		8.4	146
	1032	6	5.75	21.0	.020	.020	.006	< .001	< .001	.08	0.68		8.0	144
	1035	6.5	4.7	19.7										
	1045	7	0.6	16.8	.065	.052	.042							
	1050	8	< 0.1	14.2	.115	.099	.100	.001	.001	.02	0.68		7.8	144
	1100	10	< 0.1	12.2	.166	.154	.148							
	1105	12	< 0.1	11.8	.221	.210	.197	< .001	.001	.25	0.61		7.8	146
	1120	14	< 0.1	11.6	.236	.208	.203							
	1130	16			.242	.205	.199							
	1150	18			.242	.221	.219	.001	.002	.30	0.54		7.8	148

APPENDIX A (continued)

DATE	TIME	DEPTH METERS	DO mg/l	TEMP °C	TOTAL P. mg P/l	TOT. SOL. P. mg P/l	ORTHO P. mg P/l	NO_2-N mg N/l	NO_3-N mg N/l	NH_3-N mg N/l	ORG N mg N/l	KJN mg N/l	pH
6/27/78	1007	Surface	7.6	21.3	.018	.012	.003	< .001	.002	.07	.32	.39	8.3
	1030	2	7.5	21.3	.016	.012	.003						
	1035	4	7.3	21.3	.020	.013	.003	< .001	.001	.12	.30	.42	8.3
	1045	6	6.6	20.8	.023	.016	.006	.001	.002	.07	.37	.44	8.2
	1050	6.5	6.1	20.7									
	1100	7	3.2	19.8	.062	.057	.047						
	1105	8	0.1	14.8	.124	.104	.081	< .001	.001	.05	.33	.38	7.5
	1110	10	0.08	12.5	.164	.154	.142						
	1115	12	0.08	12.0	.211	.205	.175	.001	.001	.26	.74	1.00	7.5
	1120	14	0.08	11.9	.236	.221	.202						
		16			.252	.221	.209						
		18			.262	.224	.220	< .001	.001	.36	.10	.46	7.5
7/5/78	1045	Surface	9.5	22.2	.021	.005	.002	< .001	.005	< .01	.74	.74	8.6
	1050	2	9.5	22.2									
	1130	4	9.0	21.4									
	1130	6	6.9	20.5									
	1135	6.5	6.6	20.1	.023	.008	.003	< .001	.003	< .01	.30	.30	8.3
	1140	7	3.75	19.0									
	1145	7.5	0.6	17.5									
	1145	8	< 0.1	15.2									
	1155	10	< 0.1	12.3									
	1200	12		11.8									
	1215	14		11.8									
	1230	16											
	1235	18			.294	.239	.225	< .001	.034	.38	.24	.62	7.7

APPENDIX A (continued)

DATE	TIME	DEPTH METERS	DO mg/l	TEMP °C	TOTAL P. mg P/l	TOT. SOL. P. mg P/l	ORTHO P. mg P/l	NO_2-N mg N/l	NO_3-N mg N/l	NH_3-N mg N/l	ORG N mg N/l	KJN mg N/l	pH	ALK mg $CaCO_3$/l
7/11/78	1037	Surface	9.72	22.2	.021	.006	.002	.001	.055	.01	.85	.86	8.8	144
	1045	2	9.75	22.2										
	1045	4	9.5	22.1										
	1050	6	7.8	20.2	.020	.005	.002	.001	.019	.02	.51	.52	8.0	143
	1115	6.5	5.4	20.0										
	1130	7	4.6	19.5	.026	.015	.005							
	1135	7.5	2.3	19.0										
	1145	8	0.2	16.0	.180	.158	.145	.001	.001	.08	.44	.52	7.4	142
	1200	10	0.1	12.2	.187	.177								
	1215	12	< 0.1	12.0	.239	.221	.206	< .001	.003	.22	.64	.86	7.4	145
	1220	14		11.5	.260	.242	.219							
		16			.284	.259	.241	.001	.006	.34	.64	.98	7.4	145
		18			.302	.247	.236							
7/18/78	0945	Surface	8.65	24.0	.015	.008	< .001	.001	.001	.01	.48	.49	8.8	139
	1000	2	8.55	23.8										
	1015	4	8.4	22.5										
	1030	6	2.8	20.7	.029	.018	< .001	.001	.002	.07	.52	.59	8.1	139
	1045	6.5	1.8	20.0										
	1100	7	0.2	18.8		.026	.006							
	1115	7.5	< 0.1	17.8										
	1130	8	< 0.1	16.8	.107	.089	.058	.003	<.001	.05	.40	.45	7.5	137
	1130	10	< 0.1	12.5	.237	.234	.289							
	1145	12	< 0.1	11.9	.270	.255	.214	< .001	.001	.32	.37	.69	7.5	140
	1200	14	< 0.1	11.9	.286	.265	.231							
		16			.301	.260	.241							
	1215	18			.322	.268	.214	< .001	.001	.42	.27	.69	7.5	148

APPENDIX A (continued)

DATE	TIME	DEPTH METERS	DO mg/l	TEMP °C	TOTAL P. mg P/l	TOT. SOL. P. mg P/l	ORTHO P. mg P/l	NO_2-N mg N/l	NO_3-N mg N/l	NH_3-N mg N/l	ORG N mg N/l	KJN mg N/l	pH	ALK mg $CaCo_3$/l
7/25/78	1005	Surface	8.6	24.8	.016	.008	.003	.001	.001	.01	.49	.50	8.8	141
	1020	2	8.5	24.8										
	1030	4	8.5	24.2										
	1035	6	2.4	21.3	.037	.010	.005	.020	.030	.01	.56	.57	7.8	138
	1050	6.5	0.5	20.2										
	1100	7	0.4	20.1	.047	.035	.028							
	1105	7.5	< 0.1	18.5										
	1115	8	< 0.1	17.0	.133	.112	.102	.002	.001	.08	.30	.38	7.4	137
	1130	10	< 0.1	13.0	.256	.237	.224							
	1145	12	< 0.1	12.1	.276	.262	.247	.001	< .001	.28	.28	.56	7.4	142
	1150	14	< 0.1	11.8	.302	.270	.250							
	1210	16			.314	.285	.263							
	1230	18			.317	.295	.277	.001	.002	.43	.31	.74	7.4	143
8/1/78	1000	Surface	7.8	24.1	.024	.008	.002	.001	.001	<.01	.59	.59	8.65	148
	1015	2	7.7	24.1										
	1020	4	6.5	22.7										
	1045	6	4.5	21.9	.028	.009	.003	.007	.014	.02	.49	.51	8.3	147
	1050	6.5	3.2	21.5										
	1110	7	0.7	19.5	.070	.057	.038							
	1115	7.5	< 0.1	17.8										
	1120	8	< 0.1	17.0	.134	.107	.097	.001	< .001	.08	.79	.87	7.5	144
	1125	10	< 0.1	12.8	.265	.249	.231							
	1130	12	< 0.1	12.0	.306	.281	.256	.002	< .001	.45	.70	1.15	7.4	148
	1130	14	< 0.1	11.8	.322	.289	.266							
		16			.335	.299	.274							
		18			.341	.302	.288	.001	< .001	.56	.63	1.19	7.45	149

APPENDIX A (continued)

DATE	TIME	DEPTH (m)	DO (mg/l)	TEMP (°C)	TOTAL P. (mg P/l)	TOTAL SOL. P. (mg P/l)	ORTHO P. (mg P/l)	NO_2-N (mg N/l)	NO_3-N (mg N/l)	NH_3-N (mg N/l)	ORG N (mg N/l)	KJN (mg N/l)	pH	ALK (mg $CaCO_3$/l)
8/8/78	950	0	7.5	25.5	.018	.011	.002	<.001	<.001	<.01	.48	.48	8.6	151
	955	2	7.4	25.2										
	1015	4	6.1	23.8										
	1045	6	1.8	21.8	.020	.013	.008	.013	.091	.02	.44	.46	8.1	148
	1100	6.5	0.8	20.8										
	1110	7	0.25	20.1	.067	.049	.039							
	1125	7.5	<0.1	18.0										
	1135	8	<0.1	15.3	.166	.146	.133	.001	.003	.09	.49	.58	7.6	146
	1150	10	<0.1	12.7	.260	.241	.226							
	1200	12	<0.1	12.0	.302	.286	.266	<.001	<.001	.32	.60	.92	7.6	151
	1215	14	<0.1	11.8	.322	.291	.264							
	1225	16			.348	.298	.277							
	1230	18	<0.1		.356	.302	.277	.001	<.001	.60	.58	1.18	7.55	151
8/15/78	900	0	6.8	23.8	.018	.008	.003	<.001	.013	.01	.51	.52	8.4	149
	915	2	6.7	23.6										
	930	4	6.5	23.5										
	945	6	4.8	22.9	.024	.018	.011	.003	.027	.04	.58	.62	8.3	149
	1000	6.5	3.3	22.0										
	1010	7	0.6	20.9	.104	.072	.064							
	1015	7.5	<0.1	18.0										
	1020	8	<0.1	16.2	.185	.153	.142	<.001	<.000	.18	.84	1.02	7.6	144
	1030	10	<0.1	13.0	.294	.272	.261							
	1045	12	<0.1	12.1	.328	.306	.281	<.001	.001	.48	.64	1.12	7.5	149
	1105	14	<0.1	11.9	.354	.309	.286							
	1120	16			.361	.315	.292							
	1130	18	<0.1		.380	.325	.311	<.001	.000	.56	.68	1.24	7.5	148

APPENDIX A (continued)

DATE	TIME	DEPTH (m)	DO (mg/l)	TEMP (°C)	TOTAL P. (mg P/l)	TOTAL SOL. P. (mg P/l)	ORTHO P. (mg P/l)	NO_2-N (mg N/l)	NO_3-N (mg N/l)	NH_3-N (mg N/l)	ORG N (mg N/l)	KJN (mg N/l)	pH	ALK (mg $CaCO_3$/l)
8/22/78	900	0	7.3	22.4	.021	.009	.005	.001	<.001	<.01	.40	.40	8.2	149
	915	2	6.9	22.4										
	925	4	6.9	22.3										
	930	6	6.3	22.0	.024	.011	.006	.001	.002	<.01	.38	.38	8.1	149
	945	6.5	3.8	21.5										
	950	7	3.2	21.0	.060	.049	.044							
	955	7.5	1.4	19.0										
	1015	8	.20	17.0	.193	.163	.152	.001	.002	.16	.52	.68	7.4	144
	1020	10	<.1	13.0	.298	.273	.256							
	1030	12	<.1	12.2	.335	.309	.292	.001	<.001	.49	.29	.78	7.2	149
	1045	14	<.1	11.8	.360	.330	.316							
	1100	16		11.8	.369	.341	.324							
	1110	18	<.1	12.0	.382	.333	.319	.002	<.001	.59	.33	.92	7.2	149
8/29/78	900	0	8.2	22.5	.023	.010	.005	.001	.001	<.01	.57	.57	8.6	150
	910	2	8.1	22.5										
	915	4	7.8	22.2										
	930	6	6.8	21.9	.036	.021	.013	<.000	<.001	<.01	.39	.39	8 3	149
	945	6.5	6.1	21.7										
	1000	7	2.27	20.5	.086	.068	.064							
	1015	7.5												
	1020	8	0.25	17.8	.176	.148	.141	.001	.001	.21	.46	.67	7.6	145
	1025	10	<.1	13.5	.298	.268	.256							
	1030	12	<.1	13.2	.328	.302	.289	.001	<.001	.54	.34	.88	7.5	149
	1045	14	<.1	12.0	.379	.315	.297							
	1050	16			.400	.343	.320							
	1055	18	<.1	~12.0	.400	.336	.320	.001	<.001	.68	.25	.93	7.4	147

APPENDIX A (continued)

DATE	TIME	DEPTH (m)	DO (mg/1)	TEMP (°C)	TOTAL P. (mg P/1)	TOTAL SOL. P. (mg P/1)	ORTHO P. (mg P/1)	NO_2-N (mg N/1)	NO_3-N (mg N/1)	NH_3-N (mg N/1)	ORG N (mg N/1)	KJN (mg N/1)	pH	ALK (mg $CaCO_3$/1)
9/5/78	835	0	8.0	22.5	.023	.008	.003	.001	<.001	<.01	.39	.39	8.5	151
	840	2	7.9	22.5										
	850	4	7.5	22.5										
	910	6	5.9	22.0	.036	.011	.006	.001	<.001	<.01	.39	.39	8.3	150
	920	6.5	5.7	21.5										
	925	7	3.7	20.4	.052	.033	.030							
	930	7.5	1.3	19.9										
	950	8	.25	19.0	.120	.098	.089	.001	<.001	.02	.44	.45	7.6	147
	1000	10	<.1	13.2	.319	.291	.280							
	1020	12	<.1	12.2	.372	.343	.328	.001	<.001	.56	.37	.93	7.4	151
	1030	14	<.1	12.0	.397	.353	.332							
	1045	16			.413	.354	.336							
	1115	18	<.1	~12.0	.421	.366	.356	.001	.001	.69	.40	1.09	7.4	151
9/12/78	915	0	7.3	21.5	.031	.016	.009	<.001	<.001	<.01	.41	.41	8.4	150
	920	2	7.1	21.5										
	925	4	6.8	21.3										
	935	6	6.4	21.2	.031	.020	.011	<.001	<.001	<.01	.47	.47	8.3	150
	940	6.5	5.9	21.1										
	945	7	5.9	21.0	.031	.021	.016							
	955	7.5	4.9	20.8										
	1000	8	1.5	19.8	.148	.127	.117	<.001	<.001	.081	.37	.45	7.9	147
	1005	10	<.1	13.5	.340	.320	.297							
	1015	12	<.1	12.5	.379	.345	.324	.001	<.001	.55	.30	.85	7.5	150
	1025	14	<.1	12.0	.411	.348	.334							
	1030	16			.413	.371	.349							
	1035	18	<.1	~12.0	.439	.377	.358	.001	<.001	.66	.39	1.05	7.4	151

APPENDIX A (continued)

DATE	TIME	DEPTH (m)	DO (mg/1)	TEMP (°C)	TOTAL P. (mg P/1)	TOTAL SOL. P. (mg P/1)	ORTHO P. (mg P/1)	NO_2-N (mg N/1)	NO_3-N (mg N/1)	NH_3-N (mg N/1)	ORG N (mg N/1)	KJN (mg N/1)	pH	ALK (mg $CaCO_3$/1)
9/19/78	915	0	9.8	20.9	.039	.026	.019	<.001	.001	<.01	.30	.30	8.6	146
	920	2	10.1	20.8	.034	.023	.017	<.001	.001	<.01	.32	.32	8.35	148
	935	4	10.3	20.8	.034	.021	.016	<.001	.001	<.01	.32	.32	8.35	147
	950	6	10.2	20.7	.033	.023	.017	<.001	.001	<.01	.32	.32	8.20	147
	1000	6.5		20.7										
	1020	7		20.5	.033	.021	.017							
	1025	7.5		20.1										
	1030	8	2.2	20.1	.104	.078	.069	<.001	.001	.011	.41	.42	7.8	147
	1045	10	.13	13.8	.354	.333	.311							
	1100	12	<.01	12.8	.410	.348	.333	<.001	.001	.48	.69	1.17	7.4	150
	1115	14	<.01	12.1	.423	.358	.339							
		16	<.01		.454	.376	.353	.001	.002	.49	.97	1.46	7.4	152
	1125	18	<.01	~12.1	.476	.380	.367	.001	.001	.57	.89	1.46	7.3	151
10/17/78	845	0	7.3	20.0	.042	.028	.019	.001	.003	<.01	.45	.45	8.3	150
	850	2	7.35	20.0										
	855	4	7.1	20.0										
	900	5	7.1	20.0										
	915	6	7.1	20.0	.037	.028	.020	.001	.001	.011	.40	.41	8.2	149
	920	8	3.8	19.8	.060	.047	.041	.003	.003	.013	.42	.43	8.1	148
	930	9.5	.3	15.8										
	935	10	0.15	14.2	.400	.371	.356							
	945	12	<.1	12.5	.450	.395	.380	.002	.001	.63	.58	1.21	7.5	151
	1010	14	<.1	12.1	.512	.400	.374							
	1030	16	<.1	12.0	.515	.413	.386							
	1045	18	<.1	12.0	.546	.413	.394	.002	.001	.94	.29	1.23	7.4	154

APPENDIX A (continued)

DATE	TIME	DEPTH (m)	DO (mg/ℓ)	TEMP (°C)	TOTAL P. (mg P/ℓ)	TOTAL SOL. P. (mg P/ℓ)	ORTHO P. (mg P/ℓ)	NO_2-N (mg N/ℓ)	NO_3-N (mg N/ℓ)	NH_3-N (mg N/ℓ)	ORG N (mg N/ℓ)	KJN (mg N/ℓ)	pH	ALK (mg $CaCO_3$/ℓ)
11/14/78	1025	0	7.3	14.2	.091	.072	.061	.002	<.001	.039	.38	.42	8.0	144
	1030	2	6.8	14.1										
	1035	4	6.95	14.1										
	1045	5	6.9	14.0										
	1050	6	6.75	14.0	.093	.072	.066	<.001	<.001	.023	.38	.40	8.0	150
	1055	7			.091	.070	.066							
	1100	8	6.85	14.0	.096	.068	.066	<.001	<.001	.024	.38	.40	8.0	150
	1105	9.5	6.8	14.0										
	1110	10	6.8	14.0	.096	.078	.067							
	1120	12	1.3	13.5	.333	.302	.292	.001	<.001	.64	.35	.99	7.6	154
	1130	14	<0.1	12.0	.515	.455	.438							
	1145	16	<0.1	11.5	.592	.480	.455							
	1200	18	<0.1	11.5	.683	.546	.533	.001	.001	1.30	.34	1.64	7.3	156
12/12/78	830	0	6.7	10.9	.135	.124	.113	.002	.018	.20	.27	.47	7.8	146
	835	2	6.4	10.8										
	840	4	6.3	10.8										
	850	5	6.5	10.7										
	900	6	6.4	10.7	.133	.124	.113	.002	.016	.20	.25	.45	7.9	147
	915	7	6.3	10.8	.134	.124	.111							
	920	8	6.3	10.8	.135	.124	.114	.002	.016	.20	.25	.45	7.9	146
	925	9.5	6.4	10.8										
	930	10	6.4	10.8	.135	.124	.113							
	940	11	6.3	10.8										
	945	12	6.3	10.8	.135	.125	.113	.002	.019	.21	.24	.45	7.9	147

APPENDIX A (continued)

DATE	TIME	DEPTH (m)	DO (mg/ℓ)	TEMP (°C)	TOTAL P. (mg P/ℓ)	TOTAL SOL. P. (mg P/ℓ)	ORTHO P. (mg P/ℓ)	NO_2-N (mg N/ℓ)	NO_3-N (mg N/ℓ)	NH_3-N (mg N/ℓ)	ORG N (mg N/ℓ)	KJN (mg N/ℓ)	pH	ALK (mg $CaCo_3$/ℓ)
12/12/78	1005	13	6.3	10.8										
	1015	14	6.4	10.8	.137	.125	.113							
	1020	16	6.2	10.8	.138	.125	.111							
	1045	18	6.3	10.8	.138	.128	.114	.002	.017	.22	.28	.50	7.85	146
1/16/79	1100	0	9.6	8.9	.114	.089	.079	.003	.093	.049	.33	.38		144
	1045	2	9.5	8.9										
	1030	4	9.3	8.9										
	1025	5	9.3	8.9										
	1015	6	9.2	8.9	.115	.094	.081	.004	.091	.050	.35	.40		148
	1005	7		8.9	.115	.094	.082							
	1000	8	9.2	8.9	.119	.093	.082	.004	.085	.052	.39	.44		146
	955	9.5	9.2	8.9										
	950	10	9.0	8.9	.120	.098	.082							
	945	11	8.5	8.9										
	940	12	8.5	8.9	.128	.099	.085	.004	.103	.084	.36	.44		148
	935	13	8.3	8.9										
	925	14	8.3	8.9	.127	.098	.084							
	920	16	8.1	8.9	.139	.096	.082							
	910	18	8.1	8.9	.156	.102	.087	.004	.120	.086	.43	.52		146

APPENDIX A (continued)

DATE	TIME	DEPTH (m)	DO (mg/ℓ)	TEMP (°C)	TOTAL P. (mg P/ℓ)	TOTAL SOL. P. (mg P/ℓ)	ORTHO P. (mg P/ℓ)	NO_2-N (mg N/ℓ)	NO_3-N (mg N/ℓ)	NH_3-N (mg N/ℓ)	ORG N (mg N/ℓ)	KJN (mg N/ℓ)	pH	ALK (mg $CaCo_3$/ℓ)
2/13/79	1100	surface	12.5	10.8	.086	.068	.056	.001	.002	.012	.43	.44	8.5	144
	1055	2	12.5	10.8										
	1045	4	15.15	10.8										
	1030	5	10.9	10.8										
	1015	6	10.4	8.9	.088	.068	.058	.002	.001	<.01	.44	.44	8.3	145
	1000	7	10.5	8.4	.081	.059	.050							
	1000	8	10.0	8.5	.112	0.78	.063	.002	.002	<.01	.48	.48	8.2	144
	955	9.5	9.35	8.0										
	945	10		8.0	.083	.060	.052							
	940	11	9.15	8.0										
	930	12	9.0	8.0	.151	.111	.094	.005	.006	.035	.59	.62	8.1	144
	925	13	8.9	8.0										
	915	14	8.75	8.0	.088	.063	.056							
	910	16	9.05	8.0	.094	.065	.055							
	905	18	9.10	8.0	.166	.124	.097	.007	.014	.110	.64	.75	8.1	144
3/13/79	1100	surface	9.9	14.0										
	1050	2	9.9	14.0										
		(3)		14.0										
	1045	4	9.4	13.5										
		4.25		11.5										
		4.5	9.1	11.0										
	1030	5	8.8	10.8										
	1025	6	8.4	10.0	.067	.059	.049	<.001	.002	.011	.33	.34	8.0	144
	1020	7		9.9	.073	.063	.053							
	1015	8	7.3	9.3	.078	.067	.058	.001	.015	.054	.31	.36	7.9	143
	1000	9.5	6.0	9.0										

DATE	TIME	DEPTH (m)	DO (mg/ℓ)	TEMP (°C)	TOTAL P. (mg P/ℓ)	TOTAL SOL. P. (mg P/ℓ)	ORTHO P. (mg P/ℓ)	NO_2-N (mg N/ℓ)	NO_3-N (mg N/ℓ)	NH_3-N (mg N/ℓ)	ORG N (mg N/ℓ)	KJN (mg N/ℓ)	pH	ALK (mg $CaCo_3$/ℓ)
3/13/79	950	10		8.9	.083	.075	.064							
(Contd)	940	11	5.8	8.8										
	930	12	5.5	8.8	.093	.085	.073	.003	.026	.11	.35	.46	7.8	145
	920	13	5.2	8.7										
	915	14	5.35	8.7	.096	.085	.075							
	905	16	5.25	8.5	.098	.088	.076							
	900	18	5.2	8.5	.106	.099	.085	.004	.022	.18	.30	.48	7.6	145
4/17/79	1100	surface	9.7	16.2		.036	0.21	<.001	.002	< .01	.39	.39	8.1	142
	1050	2	9.8	16.2										
	1045	4	9.7	16.1										
	1040	5	8.95	15.9										
	1035	6	8.4	14.5	.055	.046	.036	<.001	.002	< .01	.39	.39	8.0	144
	1030	6.5	7.85	13.7										
	1020	7	6.2	12.5	.067	.059	.047							
	1020	8	4.4	11.1	.076	.071	.061	.001	.038	.01	.41	.41	7.7	144
	1015	9.5	3.05	10.5										
	1005	10		10.1	.086	.080	.070							
	1000	11	2.2	9.9										
	950	12	2.1	9.8	.091	.086	.073	.011	.154	< .01	.39	.39	7.4	142
	940	13	1.9	9.7										
	935	14	1.6	9.6	.096	.088	.076							
	925	16	1.6	9.3	.107	.099	.087							
	915	18	1.5	9.3	.112	.109	.094	.001	.242	< .01	.35	.35	7.3	146

APPENDIX A (continued)

DATE	TIME	DEPTH (m)	DO (mg/ℓ)	TEMP (°C)	TOTAL P. (mg P/ℓ)	TOTAL SOL. P. (mg P/ℓ)	ORTHO P. (mg P/ℓ)	NO_2-N (mg N/ℓ)	NO_3-N (mg N/ℓ)	NH_3-N (mg N/ℓ)	ORG N (mg N/ℓ)	KJN (mg N/ℓ)	pH	ALK (mg $CaCo_3$/ℓ)
5/14/79	1100	surface	11.3	22.9	.091	.023	.014	.001	.001	.52	2.12	2.64	8.9	130
	1055	2	10.8	18.3										
	1045	4	9.2	16.5										
	1040	5	8.7	16.2										
	1030	6	6.6	15.5	.031	.023	.017	.005	.012	.04	.37	.40	8.5	141
	1025	7	4.9	13.5	.059	.042	.040							
	1015	8	1.5	11.5	.096	.089	.081	.001	.119	<.01	.30	.30	8.1	145
	1005	9.5	0.6	10.3										
	950	10		10.0	.109	.104	.099							
	940	11	0.4	9.8										
	930	12	0.3	9.7	.119	.114	.105	.008	.195	<.01	.30	.30	7.9	145
	925	13	0.25	9.3										
	920	14	0.25	9.3	.143	.135	.120							
	910	16	0.2	9.2	.154	.143	.129							
	900	18	0.3	9.2	.161	.154	.140	.033	.167	.09	.35	.44	7.6	147

DATE	TIME	DEPTH (m)	DO (mg/ℓ)	TEMP (°C)	TOTAL P. (mg P/ℓ)	TOTAL SOL. P. (mg P/ℓ)	ORTHO P. (mg P/ℓ)	NO_2-N (mg N/ℓ)	NO_3-N (mg N/ℓ)	NH_3-N (mg N/ℓ)	ORG N (mg N/ℓ)	KJN (mg N/ℓ)	pH	ALK (mg $CaCo_3$/ℓ)
6/20/79	1110	surface	8.2	22.0	.023	.015	.006	.002	.004	.01	0.51	0.52	8.7	145
	1100	2	8.1	21.9	.023			.002	.004	.01	0.51			145
	1050	4	6.7	21.3	.023			.002	.004	.01	0.51			145
	1045	5	6.45	20.8	.023			.002	.004	.01	0.51			145
	1020	6	0.35	15.6	.070	.047	.040	.012	.146	.01	0.47	0.48	8.0	144
	1010	7	0.3	13.7	(.109)	.088	.076	.012	.146	.01	0.47	0.48	8.0	144
	1005	8	0.1	12.2	.179	.171	.157	.001	.003	.10	0.36	0.46	7.6	148
	1000	9.5	0.1	10.8	.179			.001	.003	.10	0.36			148
	950	10	0.1	10.6	.218	.210	.190	.001	.003	.10	0.36			148
	935	12	<.1	10.1	.239	.229	.216	.001	<.001	.23	0.29	0.52	7.5	150
	920	14	<.1	9.9	.252	.241	.224	.001	<.001	.34	0.28			152
	910	16	<.1	9.9	.257	.252	.227	.001	<.001	.34	0.28			152
	900	18	<.1	9.9	.267	.257	.238	.001	<.001	.34	0.28	0.62	7.4	152

APPENDIX B

LAFAYETTE RESERVOIR RUNOFF SAMPLING

Table B-1. SUMMARY OF SAMPLE COLLECTION

Sample Date	Sample Description
2 March 1978	- Total of 9 samples collected (3 samples at each of 3 stations near paved trail) - Serial sampling over 6-hr. interval.
9 March 1978	- Total of 18 samples collected. Eighteen different sites near paved trail.
11 January 1979	- Total of 18 samples collected. Eighteen different sites near paved trail.
20-22 February 1979	- Total of 24 samples collected at 3 sampling sites. - Serial sampling over 23-hr. interval.

APPENDIX B

LAFAYETTE RESERVOIR RUNOFF SAMPLING

Table B-2. SAMPLING RESULTS, 2 MARCH 1978 (SERIAL SAMPLE).

Parameter Measured									
Station	TIME	NO_3 mg/ℓ	NO_2 mg/ℓ	NH_3 mg/ℓ	KJN mg/ℓ	Org N mg/ℓ	Ortho P mg/ℓ	Dissolved P mg/ℓ	Total P mg/ℓ
1	1010	0.226	0.002	0.04	0.33	0.29	0.038	0.062	0.104
1	1315	0.172	<0.001	0.02	0.38	0.36	0.047	0.057	0.076
1	1600	0.987	0.002	0.04	0.45	0.41	0.055	0.094	0.221
2	1020	0.303	0.001	0.15	0.98	0.83	0.031	0.046	2.490
2	1320	0.277	0.001	0.02	5.60	5.58	0.062	0.078	2.810
2	1605	1.274	<0.001	0.06	3.99	3.93	0.047	0.043	3.302
3	1040	0.245	<0.001	0.05	4.67	4.62	0.034	0.098	4.992
3	1325	0.322	0.002	0.02	9.60	9.58	0.052	0.062	4.810
3	1610	0.759	<0.001	0.04	2.50	2.46	0.064	0.121	1.352

APPENDIX B

LAFAYETTE RESERVOIR RUNOFF SAMPLES

Table B-3. SUMMARY OF SAMPLING RESULTS, 9 MARCH 1978

Values Listed Represent Means of Samples
Collected at 18 Locations Around the Reservoir

	Parameter Measured							
	Ortho P mg/ℓ	Dissolved P mg/ℓ	Total P mg/ℓ	NO_2 mg/ℓ	NO_3 mg/ℓ	NH_3 mg/ℓ	KJN mg/ℓ	Org N mg/ℓ
Mean Value	0.057	0.068	1.023	0.004	0.160	0.016	3.18	3.17
(Standard Deviation)	(0.033)	(0.037)	(3.577)	(0.004)	(0.161)	(0.008)	(10.391)	(10.384)

Table B-4. SUMMARY OF SAMPLING RESULTS, 11 JANUARY 1979

Values Listed Represent Means of Samples
Collected at 18 Locations Around the Reservoir

	Parameter Measured								
	Ortho P mg/ℓ	Dissolved P mg/ℓ	Total P mg/ℓ	NO mg/ℓ	NO mg/ℓ	NH mg/ℓ	KJN mg/ℓ	Org N mg/ℓ	Total Suspended Solids mg/ℓ
Mean Value	0.107	0.129	1.215	0.002	1.614	0.019	3.41	3.39	1297.2
(Standard Deviation)	(0.070)	(0.080)	(1.561)	(0.002)	(2.891)	(0.008)	(3.91)	(3.91)	(2043.6)

APPENDIX B

LAFAYETTE RESERVOIR RUNOFF SAMPLES

Table B-5. SAMPLING RESULTS, 20-23 FEBRUARY 1979 (SERIAL SAMPLE)

Station	Date	Time	NO_3 mg/ℓ	NO_2 mg/ℓ	NH_3 mg/ℓ	KJN mg/ℓ	Org N mg/ℓ	Ortho P mg/ℓ	Dissolved P mg/ℓ	Total P mg/ℓ	Suspended Solids mg/ℓ
1	2-20	1030	0.165	0.001	0.011	0.43	0.42	0.029	0.034	0.060	21.3
1	2-20	1645	0.591	<0.001	0.017	0.27	0.25	0.059	0.079	0.252	173.0
1	2-21	745	0.778	<0.001	0.011	0.87	0.86	0.064	0.081	0.130	53.5
1	2-21	1615	0.474	<0.001	<0.010	0.85	0.85	0.041	0.055	0.081	27.1
1	2-22	815	0.305	<0.001	0.011	0.63	0.62	0.036	0.049	0.780	31.0
1	2-22	1445	0.626	<0.001	0.011	1.05	1.04	0.074	0.094	0.211	126.0
1	2-23	845	0.382	0.001	0.014	0.40	0.39	0.042	0.050	0.059	10.3
1	2-23	1600	0.363	<0.001	0.011	0.32	0.31	0.038	0.046	0.055	10.3
2	2-20	1035	0.266	<0.001	0.011	0.63	0.62	0.032	0.041	0.179	219.0
2	2-20	1650	0.464	<0.001	0.018	4.90	4.88	0.047	0.065	2.423	2816.9
2	2-21	750	0.398	<0.001	0.011	2.90	2.89	0.050	0.067	1.902	1982.0
2	2-21	1620	0.337	<0.001	<0.011	1.06	1.06	0.038	0.052	0.488	503.0
2	2-22	820	0.235	<0.001	<0.010	1.26	1.26	0.050	0.065	0.455	505.0
2	2-22	1450	0.352	<0.001	0.012	4.47	4.46	0.050	0.063	1.902	2146.7
2	2-23	850	0.280	<0.001	0.017	0.70	0.68	0.027	0.037	0.203	220.5
2	2-23	1605	0.261	<0.001	0.015	0.70	0.69	0.025	0.036	0.154	164.7
3	2-20	1045	0.337	<0.001	<0.011	0.81	0.81	0.030	0.039	0.062	-
3	2-20	1700	0.700	<0.001	0.013	2.45	2.44	0.052	0.072	0.626	695.0
3	2-21	800	0.642	<0.001	0.011	1.35	1.34	0.058	0.078	0.780	629.0
3	2-21	1630	0.649	<0.001	<0.011	0.85	0.85	0.044	0.063	0.146	80.0
3	2-22	830	0.544	<0.001	<0.010	0.75	0.75	0.039	0.052	0.117	75.3
3	2-22	1800	0.467	<0.001	0.011	1.70	1.69	0.037	0.073	0.951	912.0
3	2-23	900	0.525	<0.001	0.015	0.64	0.63	0.033	0.047	0.078	33.0
3	2-23	1610	0.509	0.001	0.011	0.56	0.55	0.032	0.044	0.073	24.25